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Modeling in Physics and Physics Education

Editors: Ed van den Berg Ton Ellermeijer Onne Slooten







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Gemeente Amsterdam



Preface

This book and CD contain almost all papers presented at the 2006 Amsterdam GIREP Conference:

The review process for papers was as follows: The chairperson of each paper session conducted a first review and recommended whether or not a paper should be published in the CD proceedings on the basis of relevance and quality and whether or not the paper should be considered for the book. A second review was conducted by reviewers after the conference. Papers receiving two positive book recommendations were accepted for the book version. Papers with one positive book recommendation went through a third review by the editors. Poster papers were reviewed by one reviewer.

All papers in the final version were posted on the web and authors were asked to check for major errors which might have slipped in somewhere in the word processing towards the final format.

This book and CD are the result of that process. Both book and CD have received an ISBN number.

The editors

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Introduction

GIREP Conference Modeling in Physics and Physics Education, Amsterdam, August 20 – 25, 2006

Ed van den Berg, Onne Slooten, and Ton Ellermeijer AMSTEL Institute Universiteit van Amsterdam

Some 260 physicists, physics educators, and teachers from over 40 countries participated in the Amsterdam 2006 Conference to remodel their thoughts on Modeling in Physics and Physics Education. Together they presented 125 papers, 90 posters, 11 workshops, and 12 plenary lectures.

Models and modeling take on different meanings in physics education. The activity of practicing physicists is centered on the development, testing, and application of mathematical models for physical phenomena (Hestenes). Modeling in physics can also be seen as creating "artificial worlds" to give insight into how real systems work, and to predict what they might do (Ogborn). In teaching models can be mainly conceptual and qualitative, or they can be mathematical. The current state of ICT allows for quite complex and realistic models to enter the classroom through Excel spreadsheets, or modeling programs like Insight, Stella, Coach and Modellus.

Over the past 20 years, there has been much R&D both in conceptual modeling and quantitative modeling. In his opening lecture David Hestenes took us at lightning speed through what we know now about the development of conceptual models in student brains and how to promote such development. He considers that mathematical modeling of the physical world should be the central theme of physics instruction and he has defined a small number of basic models, which can represent most of high school physics.

Hans Fuchs who teaches Physics to engineers, distinguishes a limited number of basic models in a different way:

First, we have to agree on which physical quantities we are going to use as the fundamental or primitive ones; on their basis other quantities are defined, and laws are expressed with their help. Second, there are the fundamental laws of balance of the quantities, which are exchanged in processes, such as momentum, charge, or amount of substance; we call these quantities substance-like. Third, we need particular laws governing the behavior of, or distinguishing between, different bodies; these laws are called constitutive relations. Last but not least, we need a means of relating different types of physical phenomena. The tool which permits us to do this is energy. We use the energy principle, i.e., the law which expresses our belief that there is a conserved quantity which appears in all phenomena, and which has a particular relationship with each of the types of processes.

Using system dynamics Fuchs shows that many areas of physics can be described with very similar quantitative models. Transport of conserved quantities whether material or immaterial (momentum) can be modeled very similarly in the typical system dynamics flow models with first order differential equations. Fuchs even illustrates the case of flow of a nonconserved quantity such as entropy.

Fuchs also discusses the metaphorical character of modeling and how the analogies used can actually become a pedagogical tool for understanding physics.

Teodoro takes issue with this "system dynamics" modeling based on the "flux, flow, and stock metaphor" which originated outside physics and becomes problematic when rates of change depend on other rates of change (acceleration) and need second order differential equations. His well known Modellus software can model physics phenomena in much simpler ways and thus has many advantages in teaching. Modellus is the software of choice for the well known British *Advancing Physics* course.

Lijnse argued that progress with respect to modeling on the pedagogical front has been very limited. He quoted a 2005 paper by Schwarz and White stating that:

There is ample evidence indicating that students may not understand the nature of models or the process of modeling even when they are engaged in creating and revising models.

And:

Furthermore, teaching students about the nature of models and the process of modeling has proven to be difficult. Direct efforts at improving modeling knowledge have met with limited success.

This problem applies to both secondary and university students. Lijnse distinguishes descriptive modeling, causal modeling, and dynamic modeling. Descriptive modeling refers to students learning to describe their experiences in science activities in terms of scientific symbols, and mathematical relations and graphs. The modeling process becomes more difficult when the modeling purpose becomes more theoretical, e.g., when we move to the teaching of causal explanations, for example, when introducing an initial particle model. Several dissertation studies in Utrecht emphasized a problem posing approach, which stresses students' metacognitive awareness of the purpose of a series of lessons, for example to develop a particle model to explain macroscopic phenomena . Question is whether the purpose is mastery of a particular model or mastery of modeling, and whether both can or cannot be handled simultaneously.

The plenary speakers and many paper and poster presenters presented their own solutions to this problem including Lijnse himself. Learning to model involves: a) simple or complicated physics that needs to be understood, b) techniques of using modeling software, c) understanding wat modeling is, and d) some mathematics. Learning all of these simultaneously might be asking too much. Perhaps if modeling is integrated with experimental work through an iteration of models and experiments....students may slowly develop a practical view of the possibilities and limitations of modeling. Then towards the end of their secondary school career, students may be ready for some explicit lessons about the nature of modeling? Thornton provides an overview of the mathematical prerequisites for modeling.

Rogers, Lawrence, and Mikelskis provided snapshots of how modeling is used in real classrooms starting at lower secondary. Rogers has been able to move much of the math into the background and making modeling quite pictorial for lower secondary students. Thornton Modeling is there to stay!

In their summary Zollman and Kühnelt compared modeling in physics education with nuclear fusion research. Both have great promise, both have shown successes in lab experiments. However, realization of this potential on a larger scale is still problematic. Zollman also emphasized that teaching should point out where a model goes wrong and every model goes wrong somewhere. The analogy with models of the nucleus is interesting. The shell model, the liquid drop model, the optical model, and the many body model all have features that are clearly wrong, yet these models have been very useful in physics. Each has its strengths and weaknesses. In teaching modeling we should pay attention to:

- what has been omitted from the model
- why the model may be useful anyway
- what the model and its limitations tell us
- where the model fails/succeeds

Finally, modeling takes time and therefore will require us to leave out some more topics from the curriculum!

Other highlights

There are many highlights in other papers. We single out some mainly to show the rich variety.

Ogborn, Taylor, Hanc and Tuleja presented exciting possibilities of applying the principle of least action in Physics. We refer to their own publication for details.

Broklova and Koupil showed software to illustrate the meaning of atomic quantum numbers in beautiful 3-D ways. The software is available on their website with instructions in English. One does have to adapt the instructions to the particular type and level of students, but the 3-D pictures and the variety of ways the software can represent them and allow us to look from different angles and make different cuts, certainly enriches the teaching of atomic quantum numbers and wave functions.

Van Gastel, Uylings and Heck show how the height of the water level in the Thames can be modeled with some simple assumptions and how one can get closer by adding refinements. All of this started with actual experience of the sea sailing first author.

Attention was also paid to the ways in which we evaluate innovations. Fuller, Wessman and Dettrick present a model of mixed methods, both qualitative and quantitative, that they used to evaluate an innovative university physics course. Gravenbergh compares their data with his experience from the Dutch Plon project.

Agnes et al. give an overview of what they call the 'altlasten' of physics. 'Altlasten' refers to the rotten and hazardous factories and infrastructure left behind by the communist regime in East Germany, which are not only useless, but also dangerous. Agnes et al. show us the 'altlasten' that prevent students from getting a good understanding of the energy concept in physics.

Sebestyen presents a very original way of looking at paintings. She shows how paintings of famous painters like Escher, Van Eyck and Dali can be used as physical models in the classroom. She also uses sound in an unconventional way: as a model for light. With a few simple examples she shows how pictures and sounds can enrich the experience for students in a science class.

This brief introduction does not do justice to the richness of the paper collection in book en on CD. Please be referred to the table of contents.

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Plenary Sessions

Models of / for Teaching Modeling

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Abstract

This paper is based on a number of design studies at Utrecht University in which modeling played an important role. The central question to be discussed is how modeling can be taught in a physics curriculum. Can it be taught in some explicit way, which goes further than the usual implicit way of just letting students take part in some modeling activities? Some examples of a so-called problem posing approach to various ways of modeling are described. It is argued that in the case of theory generating modeling no explicit modeling strategy seems to be available for teaching. However, in the case of theory applying modeling, a system of heuristic rules could be abstracted from reflection on students own modeling experiences, that could serve as a teachable global strategy for further modeling.

Introduction

My first visit to a GIREP conference was in Venice 1973. It was the time just after the famous American and British curriculum development projects in which inquiry learning had been introduced in all kinds of formats. Now its 2006 and again we're at a GIREP conference. And this time I'm even allowed to speak! About the didactics of modeling physics to put it in continental European terms. And thus you may ask, have we made any progress in teaching modeling in these 33 years?

Unfortunately, research has reported that most students still have inadequate ideas about models; e.g., Schwarz and White (2005) wrote: "*There is ample evidence indicating that students may not understand the nature of models or the process of modeling even when they are engaged in creating and revising models*". In spite of all development projects, it seems that models are still largely taught as facts. And that the attention for modeling still has remained largely implicit in much teaching. To my surprise, I even found when looking into a rather recent (1998) Dutch textbook for upper secondary physics education, that the term model was hardly used. Let alone the term modeling.

To my opinion the present focus on modeling is largely due to three main reasons. The first is the recent constructivist attention to conceptions that students bring to the classroom, which is interpreted as an example of the fact that people experience the world in terms of their mental models and modeling. A second is the present emphasis on the role of philosophy in science education, which has resulted in stressing the importance of attention for the nature of scientific knowledge and of scientific models in particular. And thirdly, the present availability of computers that has greatly enhanced the possibilities for creating and testing numerical models, both in science and in science education.

In fact in many proposals for improving teaching, these three aspects come together. As a remedy against students' possible misconceptions, students should better become involved in a modeling process, for which computers provide excellent 'affordances'. As a result of which not only students' learning about models of nature, but also about the nature of such models is supposed to improve. However, this is not at all easy to realize. As Schwarz and White (2005) write: "...teaching students about the nature of models and the process of modeling has proven to be difficult. Direct efforts at improving modeling knowledge have met with *limited success*". So that the main problem still seems to be how this can best be done. Thus we may ask: Can the teaching of models, about models and modeling be functionally integrated so that they strengthen each other? What is an appropriate role for the teacher in such teaching etc? And what can teaching for 'learning to model' if such a thing exists at all mean in practice? Is there something like a general 'modeling competence' and can this then be taught in a more explicit way than by just letting students go through some modeling experiences? These are the questions that I will focus on in the rest of my paper, drawing on our experiences in the Utrecht Centre for Science and Mathematics Education, resulting from a number of design studies in which modeling played an essential role (Vollebregt, 1998, Kortland 2001, Doorman 2005, Westra 2006, Ormel 2007).

But let's first go somewhat deeper into what some other people write about teaching modeling. Schwarz and White developed a teaching approach that should enable "students to create (computer) models that express their own theories of force and motion, evaluate their models using criteria such as accuracy and plausibility, and engage in discussions about models and the process of modeling". Thus, they seem to focus on modeling as a means for the learning of theory and models. And though they teach explicitly about the nature of models, involving meta-modeling knowledge as they call it, they do not teach an explicit modeling strategy. Their approach seems to focus on the *theory* generating role of modeling, I would say. Their teaching strategy could be considered as a moderate example of expressive modeling. This refers to a distinction that is often made in the literature, particularly in mathematics education, between expressive and explorative modeling. Ideally, in learning by expressive modeling students have to invent their own models. That is, they are in the first place supposed to express and test their own ideas about the world, but then the problem becomes how to shape those ideas into the concepts to be taught. While in learning by explorative modeling students are in the first place discovering, exploring and testing a given model, but then the question is how to connect this properly to students' ideas about the world. Or, in other words, do we lead students into the model, or the model into the students.

Hestenes (1987), however, seems to hold a different view. He writes: *"The cognitive process of applying the design principles of a theory to produce a model of some physical object or process is called model development or simply modeling."* This implies that, in this case, modeling takes place when applying an already known scientific theory (a system of design principles for modeling real objects) to solve new problems. As a consequence, he also formulates a modeling strategy, as a specific problem solving strategy, that, should be taught explicitly to students. Or, in other words, he focuses on the *theory applying role* of modeling.

These two approaches are of course not in contradiction but complementary. Both have their role to play in a curriculum that aims to teach physics by modeling. Thinking of such a curriculum, it seems also useful to make yet another distinction between four 'ways of modeling' that in some sense seem to build on each other. And in as far as the latter is true, you could maybe even speak of 'levels' of modeling. Modeling should start, I think, where students are at the beginning, i.e. with common sense. When they enter the classroom, we can say that students already possess many relevant reasoning skills. I.e., starting from a for them familiar context and from a for them relevant practical purpose, in general they are able to reason about and to appropriately reduce that context, to make relevant representations, to frame and test relevant expectations and to draw relevant conclusions. It is precisely this common sense level of modeling that we may and need to draw on in developing more scientific ways of modeling in teaching. Learning to model then boils down to something like: learning to use and extend the common sense modeling skills to new, possibly rather complex situations to be described/explained with new scientific conceptual models, possibly involving new modeling strategies and techniques. It seems obvious that such a learning goal cannot be reached in one stroke, but that it requires permanent attention in a long-term teaching trajectory. I cannot delineate this trajectory here in any detail, but will restrict myself to describing examples of teaching the other three ways of modeling, that can be seen as successive stations along the road. So I will discuss examples of descriptive, causal and dynamical modeling respectively.

Symbolizing and descriptive modeling

A first step on the road of learning to make scientific representations of our physical experience is to learn to describe that experience in terms of scientific symbols, and mathematical relations and graphs. Doorman (2005) studied this in a mathematics lesson series on symbolizing and modeling motion. *'From trace graphs to instantaneous change'* as he

called it. It was meant to be done from an expressive perspective, or as 'guided reinvention' as he calls it in line with the views of Freudenthal, the late Dutch mathematics educator. However, in designing expressive teaching activities it is always difficult to find the right subtle balance between providing appropriate guidance and giving appropriate construction freedom. If the freedom is too large, this may result in so much diversity in students' expressions that the teacher is no longer able to productively deal with them. And if the guidance is too strict, then students are no longer expressing their views, but mainly trying to discover what the teacher or the textbook might mean. I will not go into any details but only mention that Doorman did let students make extensive use of trace graphs, discrete displacements, bar graphs, and continuous graphs, in looking for patterns to describe and predict rather familiar one-dimensional motion situations. The required models were not taught directly in their final form, but gradually emerged during the learning process, to a large extent as a result of students' own modeling activities. They looked for patterns and regularities, and for appropriate ways to depict them, using some specially developed software. We can interpret the successive ways of description as a range of successive intermediate models. A new model is first developed as a model OF a situation, to become itself subsequently a model FOR further conceptual modeling. Given a clear purpose, students' reasoning was meant to start from concrete experience and to remain to be rooted in it during this process of meaning making and tool construction. Thus it was tried with some success to avoid some usual learning difficulties with graphing and kinematics. From the fact that no quality difference in students discourse appeared to be noticeable from classes that had or had not already been taught a regular 'direct' kinematics course, it may be concluded that such a gradual modeling approach has something important to add regarding understanding.

Causal modeling

However, the modeling process becomes more difficult when the modeling purpose becomes more theoretical, e.g., when we move to the teaching of causal explanations, as, e.g., when introducing an initial particle model. Vollebregt (1998) and Klaassen designed a lesson series for that purpose from, what we call, a *problem posing perspective*. A problem posing approach aims to promote that students have *content related* motives for their learning activities, at any time during a learning process. Or, in other words, ideally they always should be aware of the content related point of what they are doing. That this is not at all a self evident requirement was adequately expressed by Gunstone (1992) when he wrote: "*This problem of students not knowing the purpose(s) of what they are doing, even when they have been told, is perfectly familiar to any of us who have spent time teaching.*" Students often carry out learning activities according to their number (*I dunno, I never really thought about*)

it...just doing it... its 8.5...just got to do different numbers) as being told by the teacher, without knowing what learning road they are walking on and what the respective activities are supposed to contribute to that goal. Just as teachers usually do not worry enough about making this road clear to their students. We think this to be rather unfortunate for a successful learning process.

The didactical structure that is based on Vollebregt's work can be depicted in three columns: Models of nature, Nature of models and *Motives.* So, the structure depicts in fact two coupled teaching-learning processes in which students are supposed to learn about a particular model of nature, and about the nature of that model in a functionally integrated way. I.e., both learning processes are intertwined and driven by motives that may be made to emerge naturally. The arrows indicate the designed story line that the teaching process is supposed to follow. This teaching process should thus more or less be experienced as a coherent activity with a clear direction and purpose and not as a series of independent activities. The final structure shows some interesting points that are of more general importance, I think. First, it appears to be crucial to give ample attention to an orientation period, from which the purpose of the lesson sequence should clearly emerge, i.e. a global motive. In this case, this purpose, the explanation of macroscopic behavior of matter, involves in particular the development of a theoretical 'state of mind', i.e. the willingness to understand the (macroscopic) rules of nature at a deeper level. Together with the common sense clue (or advance organizer) that we often feel that we understand the working of something (machines, a human body) when we know how this working results from the functioning of its parts. Then, the global motive is narrowed down and a particular knowledge need is formulated (a first local motive). In the study of Vollebregt this concerned the behavior of gases and the explanation of the gas laws.

A second point to note is the introduction of the *germ* of a particle model (imagine that a gas behaves like a bunch of small bouncing balls). At this point we made the choice not to go for expressive modeling, i.e. to let students make their own particle model, but to go for the further exploration of a teacher-introduced model. The reason is the following. From the literature we knew that others had followed the expressive path. They asked students to design their own particle model. This resulted, quite naturally, in almost all students starting with particles as just 'tiny pieces', i.e. small pieces of matter that still have all the macroscopic properties. However, this meant that somewhere during the teaching process, teachers had to tell students, without a clear reason, that their model was not adequate and that scientists used a quite different particle model, which was then introduced.

Figure 1



Instead, as already said, we introduced an analogy from the start, *to put students* directly *on the right track*. And to let them follow and explore the consequences of that track and develop gradually more

confidence in it. First by connecting variables as volume and pressure to space to move in and collisions. Then, the coupling of temperature to speed got ample attention. And although the teaching process should still give many opportunities for students to express their ideas, this is now done within the borders of an explorative trajectory. This means that the students are not so much invited to express their ideas about the world, but to express their ideas about and to reason with the suggestions and proposals introduced by the teacher.

Starting from a just-like-bouncing-balls analogy had another fruitful consequence. Students first accepted the challenge to explain the behavior of gases with this model. However, after some lessons this quite understandably led to the question: what's the use of all this thinking and reasoning if this analogy does not make sense. If a gas does not really consist of small 'balls'. Thus providing a clear motive to discuss what it means for this ball-model to 'be realistic', i.e. to be simple, considered fruitful, consistent, empirically adequate, etc. And that a particle-model means that we try to explain macroscopic change by means of motion of unchangeable small balls. This leads to questions like: if they really exist why can't they be seen, and how can they keep moving, etc., which lead to further exploration. In fact, in this case, the need for developing metamodelling knowledge is functionally integrated in the teaching process, and not an additional extra, as e.g. in the case of Schwarz and White. Thus, in a careful designed lesson sequence, teacher and students appeared to be able to go a long way in developing and testing an introductory particle model, as well as in reflecting on the nature of that model. The sequence was rounded of with reflecting on the question in what way the final model was in line with what the global motive required, i.e. explaining matter at a deeper level. To underline the value of what was achieved it was indicated that the final model was more or less the same as proposed by Clausius in 1857. Clausius, however, also proposed that some of his particles consisted of clusters of other particles, which we now call atoms and molecules, which provides an outlook for the next step in particle modeling.

In Vollebregt's teaching sequence, we thought it appropriate that students themselves actually had to take part in a modeling process, but at that time, this was considered to be a *means*, i.e. an adequate constructivist-inspired teaching strategy, and not yet a *goal* in itself, i.e., learning to model. Nevertheless, the rounding off session also meant to reflect on the process of modeling, i.e. it was meant to make them realize that this process was more or less comparable to what scientists do. On second thought however, I think that we have to say that this part was an incorrect rounding off. Something that we did feel already then, however without being able to give this uneasy feeling a clear name. And not only because it didn't function properly in practice, as students didn't really see the point of it. In retrospect, I think that the problem is that we mixed

up two different things. I.e. making a product, a model, and the process of making that product, modeling. In making a model it is natural to ask questions about the quality of that model, thus to reflect on its characteristics. Does it do what it is supposed to do. I.e., in a problem posing approach the making of a model and reflecting on the nature of that model can be functionally coupled. In this theoretical case, this meant that the model itself was developed in functional alternation with (rather basic) reflections on epistemological and ontological aspects of the model. However, a problem posing reflection on the general nature of the modeling *process* asks for a separate motive. And thus also for a separate orientation in order to prevent that this reflection cannot really make sense to students. In our structure these aspects are not yet properly accounted for.

Now one could ask about the purpose of such a process of reflection. Is it just to give some more insight into how science works or is it also because it could students in some explicit sense 'teach to model'. In fact, modeling at this theoretical level, largely consists of framing creative adequate conceptual hypotheses and test them by means of disciplined critical logical reasoning in view of the evidence available. It seems fruitful to make students aware of this nature that may contribute to developing a critical 'scientific attitude', but it is doubtful whether this will lead to something what you might call 'learning new transferable modeling skills'. So, we may conclude that in theory generating modeling, i.e., in the context of discovery to put it in philosophical terms, no explicit teachable modeling strategy seems to be possible, apart from dealing with epistemic virtues. These may be considered as the boundary conditions for the modeling process. When properly integrated in the teaching-learning process, such virtues have a natural role to play. We found this also in another study (Westra, 2006) in which students had to model the orbit of planets using either Newton's or Kepler's theory. Students found it rather self evident, once being put on the right track, to use epistemic values as plausibility, empirical adequacy, consistency, generality as criteria for trying to decide between such rival theoretical possibilities.

Dynamical modeling

However, our conclusions on the explicit teaching of modeling may differ when we deal with theory applying modeling, as already indicated, as, e.g., in the case of dynamical modeling. Figure 2



Before going into this issue, let me first elaborate a bit on the place of dynamical modeling in our physics curriculum. Dynamical modeling has been around since the DMS-program of the eighties, but it still has not got a real foothold in Dutch physics education. A main reason may be that the regular intra-curriculum applications seem to be rather restricted, i.e., some mechanics, the capacitor, heat flow and radioactive decay. Or in other words, time is not a variable in our curriculum. In view of the present role of computer modeling in science it could however be argued that dynamical modeling should get much more curriculum attention. A proper final aim for such a curriculum strand could be to give students sufficient insight in how large scale computer models are designed and succeed in making predictions. To get an idea of the feasibility of this aim we developed an extracurricular lesson sequence on predicting the future temperature of the earth, in view of the uncertainty about the warming up of our planet and climate changes that may go with it. Our aim was to let students get a feeling about how climate scientists work on such an important practical problem and why such diversity in predictions exists, even in spite of the use of 'exact' computers. The following problemposing story line may give an idea of what we are trying. This structure should be regarded as still under construction. First I want to emphasize that we are dealing here with a theory-applying modeling process for a practical purpose. Though many details of the problem situation are unknown to our students, the basic theoretical concepts to be applied are known. And if additional theoretical knowledge is needed it is first studied and subsequently applied to model the relevant problem situation. The purpose of the modeling process is this time the solution a practical problem, the prediction of the future temperature, which explains the focus on the reliability and validity of the models. To what extent is this problem validly and reliably solved, thus on methodological aspects. Thus, the required modeling process has much in common with what Hestenes (1987) described as modeling as a specific problem solving strategy.

The topic appears to be feasible though not without problems. More than for regular curriculum topics, this extracurricular topic has a kind of bootstrap structure. Students should start with reducing reality to a very much-simplified first physical model, but lack the necessary experience and situational knowledge to do so. In fact, the first models are precisely intended to provide them with such knowledge and to set them on the right track. The role of the teachers was therefore at first instance more of showing and explicating the how and why of tackling this problem. Often students appeared to be very active at the computer level, however, without paying sufficient attention to the physics of their models. This may explain that little numerical modeling transfer appeared to occur in a next, in fact much simpler, task on modeling radioactivity. This strengthened the idea that to foster such a modeling transfer a procedure should be worked out and taught in some way. This idea also resulted from the analogy with the work of Kortland (2001) who came to the conclusion that for the teaching of decision making in social-scientific issues, it seems to be appropriate to let students, in reflecting on their own decision making experience, end up with an explicated procedure as a

metacognitive instrument for acting in subsequent decision making situations

This then poses the question how this modeling procedure can best be formulated and be taught. My guess would be that this could be done as a system of heuristic rules. Research on problem solving, however, has shown that direct teaching of problem solving heuristics has little effect. Better results may be expected if the heuristic stems from reflection on students' own modeling experience. Such a system might provide the required insight in how computer modeling 'works' and it might enhance the possibility that students tackle a next problem in a more structured way. Although it is always the case that the real content-bound creative steps in a modeling process cannot be *forced* to take place, and that the actual process is always strongly embedded in and governed by the actual content at stake, a system of heuristic rules can help to reflectively structure and repair the modeling process when its progress has become

Figure 3

Contextualized modeling (modeling nature)

Motives

Decontextualised modeling (nature of modeling)

An orientation on the use of large scale model predictions, that depend in some important way on the use of computers



new models

problematic. A didactical structure that aims for the explicitation of such a modeling heuristic should start, I think, with an orientation in which the *modeling procedure itself* is problematised as a learning goal rather than the *conceptual problem* to be modeled.. Thus making it relevant for students to finish with a reflective explicitation of that procedure (fig.3).

What could such a heuristic instrument consist of? Of course, this can be formulated at a number of levels of detail, but to give a rather general idea, we think that it should include the following categories: 1. *Analysis and reduction*:

Analyze and reduce the problem situation in terms of its possibly applicable theories, i.e. determine the appropriate system, its main objects, variables, known and unknown relations;

Analyze the problem in terms of its dynamical characteristics: what are main influences and what their effects;

2. Problem solving trajectory:

Divide the problem into a series of subsequently solvable partial problems;

Start with a reduction to a simplified largely known system and model;

Get a qualitative idea of how that system behaves; in particular as regards feedback loops;

3. Numerical model construction

Implement the model, i.e.: construct the necessary difference equations, determine an adequate time step-size and an adequate set of starting values;

4. Test and evaluation

Test and evaluate the behavior of that model in the light of the first partial problem; determine its accuracy, in particular as regards uncertainties in parameters and numerical approximations;

5. *Fine tuning and adaptation*

Revise it in view of the next partial problem;

6. Evaluation

Repeat this cycle till the final model is considered adequate in view of the main problem.

So far we have no experience to judge whether the implementation of such a set of heuristics can really foster some procedural transfer. As already said, it should be the outcome of reflective activities so that students should recognize that this set reflects the procedure that they have successfully followed, be it with the guidance of the teacher. As this set presupposes experiential knowledge about coupled feedback processes and numerical procedures, it should better not be the result of one single modeling activity, but be gradually built up and applied at the same time in a series of modeling activities. The regular curriculum topics could provide this preparation, provided that their didactical structures are adapted to this role. Thus we may come to speak of an explicit numerical modeling learning trajectory that does more than simply letting students do some numerical modeling activities without having a clear purpose.

Teacher problems

Now you may ask whether these ideas have any relation with the reality of teaching practice. Let me then first stress that we have tried most of them out, though of course not without difficulties. These difficulties can be summarized into two main categories: i.e. those dealing with giving students sufficient construction freedom, (as is well documented for constructivist-inspired teaching), and those dealing with the problem posing character of our teaching approach.

As regards providing sufficient construction space, most teachers were too quickly inclined to provide students with the right answers and had great difficulty in explaining to students the background and reasons of what they were doing. So they paid attention to the facts of the models, but not to why the models are as they are. Or, in other words, they paid attention to the models but not to the modeling. We also found it to be quite difficult for teachers to pay adequate attention to reflective activities, in particular as regards the problem posing character, such as: what have we found? Did we reach our goal? What remains to be done? Etc. Or, in other words, to let the story line evolve as a real storyline and the motives emerge and play their role. Apparently, a strong tension exists, even for experienced teachers, between on the one hand taking the lead and telling the facts and on the other guiding students adequately in letting them perform, and making them see the point of the required modeling activities (Lijnse, 2005).

Concluding hypotheses

So far I have only dealt with three models of teaching modeling. That is an insufficient experiential base to draw any strong conclusion. Only some hypotheses can be formulated. In the above I have argued for a curriculum perspective on modeling, making distinctions between expressive and explorative modeling, theory generating and theory applying modeling, and between common sense, descriptive, causal and numerical modeling. In a well-designed modeling curriculum, all these ways of modeling should have their appropriate place and function. In addition I have argued that a well-designed problem posing teachinglearning sequence enables us to make a functional coupling between the development of a model and reflection on the nature of that model. In particular: theory generating modeling could gradually lead to functional knowledge of the epistemological boundary conditions for disciplined scientific reasoning; theory applying modeling could gradually lead to the development and functional implementation of a system of modeling heuristics. Providing students with a clear and adequate purpose for their learning processes seems to be the decisive characteristic for such

functionalities. However, making this purpose to be a leading thread in students learning, asks from teachers a rather important change, as in general they are not used to teaching both at a didactical *and* a meta-didactical level, i.e. they are not used to paying attention to the required reflective teaching activities.

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Notes for a Modeling Theory of Science, Cognition and Instruction

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Abstract: Modeling Theory provides common ground for interdisciplinary research in science education and the many branches of cognitive science, with implications for scientific practice, instructional design, and connections between science, mathematics and common sense.

I. Introduction

During the last two decades *Physics Education Research* (PER) has emerged as a viable sub-discipline of physics, with faculty in physics departments specializing in research on learning and teaching physics. There is still plenty of resistance to PER from hard-nosed physicists

To the grand philosophical question: "*What is man*?" Aristotle answered: "*Man is a rational animal.*" Modeling Theory offers a new answer: "*Man is a modeling animal*!" **Homo modelus!**

who are suspicious of any research that smacks of education, psychology or philosophy. However, that is countered by a growing body of results documenting deficiencies in traditional physics instruction and significant improvements with PER-based pedagogy. Overall, PER supports the general conclusion that *science content cannot be separated from pedagogy* in the design of effective science instruction. Student learning depends as much on structure and organization of subject matter as on the mode of student engagement. For this reason, science education research *must* be located in science departments and not consigned to colleges of education.

As one of the players in PER from its beginning, my main concern has been to establish a scientific theory of instruction to guide research and practice. Drawing on my own experience as a research scientist, I identified construction and use of conceptual models as central to scientific research and practice, so I adopted it as the thematic core for a MODELING THEORY of science instruction. From the beginning, it was clear that Modeling Theory had to address cognition and learning in everyday life as well as in science, so it required development of a model-based epistemology and philosophy of science. Thus began a theory-driven MODELING RESEARCH PROGRAM: Applying the theory to design curriculum and instruction, evaluating results, and revising theory and teaching methods accordingly. Fig. 1 provides an overview of the program.

Section II reviews evolution of the Modeling Research Program. Concurrent evolution of Cognitive Science is outlined in Section III. Then comes the main purpose of this paper: To lay foundations for a common modeling theory in cognitive science and science education to drive symbiotic research in both fields. Specific research in both fields is then directed toward a unified account of cognition in common sense, science and mathematics. This opens enormous opportunities for science education research that I hope some readers will be induced to pursue.

Of course, I am not alone in recognizing the importance of *models and modeling* in science, cognition, and instruction. Since this theme cuts across the whole of science, I have surely overlooked many important insights. I can only hope that this paper contributes to a broader dialog if not to common research objectives.



II. Evolution of Modeling Instruction

My abiding interest in questions about cognition and epistemology in science and mathematics was initiated by undergraduate studies in philosophy. In 1956 I switched to graduate studies in physics with the hope of finding some answers. By 1976 I had established a productive research program in theoretical physics and mathematics, which, I am pleased to say, is still flourishing today [1]. About that time, activities of my colleagues Richard Stoner, Bill Tillery and Anton Lawson provoked my interest in problems of student learning. The result was my first article advocating Physics Education Research [2].

I was soon forced to follow my own advice by the responsibility of directing PER doctoral dissertations for two outstanding graduate students, Ibrahim Halloun and Malcolm Wells. Halloun started about a year before Wells. In my interaction with them, two major research themes emerged: First, effects on student learning of organizing instruction about models and modeling; Second, effects of instruction on student preconceptions about physics.

The Modeling Instruction theme came easy. I was already convinced of the central role of modeling in physics research, and I had nearly completed an advanced monograph-textbook on classical mechanics with a modeling emphasis [12]. So, with Halloun as helpful teaching assistant, I conducted several years of experiments with modeling in my introductory physics courses.

The second theme was more problematic. I was led to focus on modes of student thinking by numerous discussions with Richard Stoner about results from exams in his introductory physics course. His exam questions called for qualitative answers only, because he believed that is a better indicator of physics understanding than quantitative problem solving. However, despite his heroic efforts to improve every aspect of his course, from the design of labs and problem solving activities to personal interaction with students, class average scores on his exams remained consistently below 40%. In our lengthy discussions of student responses to his questions, I was struck by what they revealed about student thinking and its divergence from the physics he was trying to teach. So I resolved to design a test to evaluate the discrepancy systematically. During the next several years I encountered numerous hints in the literature on what to include. When Halloun arrived, I turned the project over to him to complete the hard work of designing test items, validating the test and analyzing test results from a large body of students.

The results [3, 4] were a stunning surprise! surprising even me! so stunning that the journal editor accelerated publication! With subsequent improvements [5], the test is now known as the *Force Concept Inventory* (FCI), but that has only consolidated and enhanced the initial results. Instructional implications are discussed below in connection with recent developments. For the moment, it suffices to know that the FCI was immediately recognized as a reliable instrument for evaluating the effectiveness of introductory physics instruction in both high school and college.

Five major papers [6-10] have been published on Modeling Theory and its application to instruction. These papers provide the theoretical backbone for the *Modeling Instruction Project* [11], which is arguably the most successful program for high school physics reform in the U.S. if not the world. Since the papers have been seldom noted outside that project, a few words about what they offer is in order.

The first paper [6] provides the initial theoretical foundation for Modeling Theory and its relation to cognitive science. As *modeling* has become a popular theme in science education in recent years, it may be hard to understand the resistance it met in 1985 when my paper was first submitted. Publication was delayed for two years by vehement objections of a referee who was finally overruled by the editor. Subsequently, the paper was dismissed as mere speculation by empiricists in the PER community, despite the fact that it was accompanied by a paper documenting successful application to instruction. Nevertheless, this paper provided the initial conceptual framework for all
subsequent developments in modeling instruction. It must be admitted, though, the paper is a difficult read, more appropriate for researchers than teachers.

Paper [7] is my personal favorite in the lot, because it exorcises the accumulated positivist contamination of Newtonian physics in favor of a modelcentered cognitive account. For the first time it breaks with tradition to formulate all six of Newton's laws. This is important pedagogically, because all six laws were needed for complete coverage of the "Force concept" in designing the FCI [5]. Moreover, explicit formulation of the Zeroth Law (about space and time) should interest all physicists, because that is the part of Newtonian physics that was changed by relativity theory. Beyond that, the paper shows that Newton consciously employed basic modeling techniques with great skill and insight. Indeed, Newton can be credited with formulating the first set of rules for MODELING GAMES that scientists have been playing ever since.

Paper [11] applies Modeling Theory to instructional design, especially the design of software to facilitate modeling activities. Unfortunately, the R&D necessary to build such software is very expensive, and funding sources are still not geared to support it.

In contrast to the preceding theoretical emphasis, papers [8, 9] are aimed at practicing teachers. Paper [8] describes the results of Wells' doctoral thesis, along with instructional design that he and I worked out together and his brilliant innovations in modeling discourse management. His invention of the portable *whiteboard* to organize student discourse is propagating to classrooms throughout the world. Sadly, terminal illness prevented him from contributing to this account of his work.

Wells' doctoral research deserves recognition as one of the most successful and significant pedagogical experiments ever conducted. He came to me as an accomplished teacher with 30 years experience who had explored every available teaching resource. He had already created a complete system of activities to support student-centered inquiry that fulfills every recommendation of the National Science Education Standards today. Still he was unsatisfied. Stunned by the performance of his students on the FCI-precursor, he resolved to adapt to high school the ideas of modeling instruction that Halloun and I were experimenting with in college. The controls for his experiment were exceptional. As one control, he had complete data on performance of his own students without modeling. Classroom activities for treatment and control groups were identical. The only difference was that discourse and activities were focused on models with emphasis on eliciting and evaluating the students' own ideas. As a second control, posttest results for the treatment group were compared to a well-matched group taught by traditional methods over the same time period. The comparative performance gains of his students were unprecedented. However, I am absolutely confident of their validity, because they have been duplicated many times, not only by Wells but others that followed.

I was so impressed with Wells' results that I obtained in 1989 a grant from the U.S. *National Science Foundation*, to help him develop *Modeling Workshops* to inspire and enable other teachers to duplicate his feat. Thus began the *Modeling Instruction Project*, which, with continuous NSF support, has evolved through several stages with progressively broader implications for science education reform throughout the United States. Details are available at the project website [11]. None of this, including my own involvement, would have happened without the pioneering influence of Malcolm Wells.

III. Evolution of Cognitive Science

Cognitive science grew up in parallel with PER and Modeling Theory. With the aim of connecting the strands, let me describe the emergence of cognitive science from the perspective of one who has followed these developments from the beginning. Of course, the mysteries of the human thought have been the subject of philosophical contemplation since ancient times, but sufficient empirical and theoretical resources to support a genuine science of mind have been assembled only recently. Box 1 outlines the main points I want to make.

I regard the *formalist* movement in mathematics as an essential component in the evolution of *mathematics as the science of structure*, which is a central theme in our formulation of Modeling Theory below. Axioms are often dismissed as mathematical niceties, inessential to science. But it should be recognized that axioms are essential to Euclidean geometry, and without geometry there is no science. I believe that the central figure in the formalist movement, David Hilbert, was the first to recognize that axioms are actually definitions! *Axioms define the structure in a mathematical system, and structure makes rational inference possible*!

Equally important to science is the operational structure of scientific measurement, for this is essential to relate theoretical structures to experiential structures in the physical world. This point has been made most emphatically by physicist Percy Bridgeman, with his concept of *operational definitions* for physical quantities (but see [7] for qualifications). However, to my mind, the deepest analysis of scientific measurement has been made by Henri Poincaré, who explained how measurement conventions profoundly influence theoretical conceptions. In particular, he claimed that curvature of physical space is not a fact of nature independent of how measurements are defined. This claim has long been inconclusively debated in philosophical circles, but recently it received spectacular confirmation [14].

Following a long tradition in rationalist philosophy, the formalist movement in mathematics and logic has been widely construed as the foundation for a theory of mind, especially in Anglo-American analytic philosophy. This is an egregious mistake that has been roundly criticized by George Lakoff and Mark Johnson [17-21] in the light of recent developments in cognitive science. Even so, as already suggested, formalist notions play an important role in characterizing structure in cognition.

The creation of serial computers can be construed as technological implementation of operational structures developed in the formalist tradition. It soon stimulated the creation of *information processing psychology*, with the

notion that cognition is all about symbol processing. I was right up to date in applying this egregious mistake to physics teaching [2]. Even so, most of the important research results and insights that I reported survive reinterpretation when the confusion between cognition and symbol processing is straightened out. Symbol processing is still a central idea in computer science and Artificial Intelligence (AI), but only the ill-informed confuse it with cognitive processes.

Box 1: Emergence of Cognitive Science I. Scientific Precursors • Formalist mathematics and logic (~1850-1940) - axioms & standards for rigorous proof - reasoning by rules and algorithms • Operationalism (Bridgeman, 1930) • Conventionalism (Poincaré, 1902) • Gestalt psychology (~1915-1940) • Genetic Epistemology (Piaget, ~1930-1960) II. Emergence of computers and computer science (~1945-1970) implementing operational structures **III. First Generation Cognitive Science** (~1960-1980) • "Brain is a serial computer" metaphor • "Mind is a computer software system" • Information processing psychology & AI – Thinking is symbol manipulation - functionalism (details about the brain irrelevant) IV. Second Generation Cognitive Science (~1983--) • Neural network level - Brain is a massively parallel dynamical system - Thinking is pattern processing • Cognitive phenomenology at the functional level: empirical evidence for mental modeling is accumulating rapidly from many sources.

I tried to link the

dates in Box 1 to significant events in each category. I selected the date 1983 for the onset of second generation cognitive science, because I had the privilege of co-organizing the very first conference devoted exclusively to what is now known as *cognitive neuroscience*. It still took several years to overcome the heavy empiricist bias of the neuroscience community and establish neural network modeling as a respectable activity in the field. The consequence has been a revolution in thinking about thinking that we aim to exploit.

IV. Modeling Research in Cognitive Science

With its promise for a universal science of mind, research in cognitive science cuts across every scientific discipline and beyond. Box 2 lists research that I see as highly relevant to the Modeling Theory I am promoting. The list is illustrative only, as many of my favorites are omitted. These scientists are so productive that it is impractical to cite even their most important work. Instead, I call attention to the various research themes, which will be expanded with citations when specifics are discussed.

References [15, 16] provide an entrée to the important work of Giere, Nercessian and Gentner, which has so much in common with my own thinking that it may be hard to believe it developed independently. This illustrates the fact that significant ideas are implicit in the culture of science waiting for investigators to explicate and cultivate as their own.

In sections to follow, I emphasize alignment of Modeling Theory with Cognitive Linguistics, especially as expounded by George Lakoff [17-20].

Language is a window to the mind, and linguistic research has distilled a vast corpus of data to deep insights into structure and use of language. My objective is to apply these insights to understanding cognition in science and mathematics. Cognitive Linguistics makes this possible, because it is a reconstruction of linguistic theory aligned with the recent revolution in Cognitive Science.

V. Constraints from Cognitive Neuroscience

Cognitive neuroscience is concerned with explaining cognition as a function of the brain. It bridges the interface between psychology and biology. The problem is to match cognitive theory at the psychological level with neural network theory at the biological level. Already there is considerable evidence supporting the *working* hypothesis that cognition (at the psychological level) is grounded in the sensorymotor system (at the biological level). The evidence is of three kinds:

- <u>Soft constraints</u>: Validated models of cognitive structure from cognitive science, especially cognitive linguistics.
- <u>Hard constraints</u>: Identification of

Box 2: Modeling Research in Cognitive Science

Philosophy of Science Ronald Giere (Model-based philosophy of science) Jon Barwise (Deductive inference from diagrams)

History and Sociology of Science Thomas Kuhn (Research driven by Exemplars) Nancy Nercessian (Maxwell's analogical modeling)

Cognitive Psychology Dedre Gentner (Analogical reasoning) Philip Johnson-Laird (Inference with mental models) Barbara Tversky (Spatial mental models vs. visual imagery)

Cognitive Linguistics

George Lakoff (Metaphors & radial categories) Ronald Langacker (Cognitive grammar & image schemas)

Cognitive Neuroscience Michael O'Keeffe (Hippocampus as a Cognitive Map) Stephen Grossberg (Neural network theory)

Stephen Grossberg (Neural network theory)

Physics Education Research Andy diSessa (Phenomenological primitives) John Clement (Bridging analogies) Information & Design Sciences UML: Universal Modeling Language & Object-Oriented Programming

specific neural architectures and mechanisms sufficient to support cognition and memory.

• *Evolutionary constraint*: A plausible account of how the brain could have evolved to support cognition.

A few comments will help fix some of the issues.

Biology tells us that brains evolved adaptively to enable navigation to find food and respond to threats. Perception and action are surely grounded in identifiable brain structures of the sensory-motor system. However, no comparable brain structures specialized for cognition have been identified. This strongly suggests that cognition too is grounded in the sensory-motor system. The main question is then: what adaptations and extensions of the sensorymotor system are necessary to support cognition?

I hold that introspection, despite its bad scientific reputation, is a crucial source of information about cognition that has been systematically explored by philosophers, linguists and mathematicians for ages. As Kant was first to realize and Lakoff has recently elaborated [20], the very structure of mathematics is shaped by hard constraints on the way we think. A major conclusion is that geometric concepts (grounded in the sensory-motor system) are the prime source of relational structures in mathematical systems.

I am in general agreement with Mark Johnson's NeoKantian account of cognition [21], which draws on soft constraints from Cognitive Linguistics. But it needs support by reconciliation with hard constraints from sensory-motor neuroscience. That defines a promising direction for research in Cognitive Neuroscience. Let me reiterate my firm opinion [6] that the research program of Stephen Grossberg provides the best theoretical resources to pursue it.

VI. System, Model & Theory; Structure & Morphism

The terms 'system' and 'model' have been ubiquitous in science and engineering since the middle of the twentieth century. Mostly these terms are used informally, so their meanings are quite variable. But for the purposes of Modeling Theory, we need to define them as sharply as possible. Without duplicating my lengthy discussions of this matter before [7-10], let me reiterate some key points with

Box 3: five type	A conceptual MODEL is defined by specifying es of structure:
(a) syste	mic structure:
•	<i>composition</i> (internal parts (objects) in the
system)	
•	environment (external agents linked to the
system)	· -
•	connections (external and internal links)
(b) geon	netric structure:
•	<i>position</i> with respect to a reference frame
(external	1)
•	<i>configuration</i> (geometric relations among the
parts)	
(c) object	ct structure:
•	intrinsic properties of the parts
(d) inter	action structure:
•	properties of (causal) links
(e) temp	ooral (event) structure:
•	temporal change in structure of the system

an eye to preparing a deeper connection to cognitive theory in the next section.

I define a **SYSTEM** *as a set of related objects*. Systems can be of any kind depending on the kind of object. A system itself is an object, and the objects of which it is composed may be systems. In a *conceptual system* the objects are *concepts*. In a *material system* the objects are material *things*. Unless otherwise indicated, we assume that the systems we are talking about are

material systems. A material system can be classified as physical, chemical or biological, depending on relations and properties attributed to the objects.

The **STRUCTURE** of a system is defined as the set of relations among objects in the system. This includes the relation of "belonging to," which specifies COMPOSITION, the set of objects belonging to the system. A universal finding of science is that all material systems have geometric, causal and temporal structure, and no other (metaphysical) properties are needed to account for their behavior. According to Modeling Theory, science comes to know objects in the real world not by direct observation, but by constructing conceptual models to interpret observations and represent the objects in the mind. This epistemological precept is called *Constructive Realism* by philosopher Ronald Giere.

I define a conceptual **MODEL** as a *representation of structure* in a material system, which may be real or imaginary. The *possible* types of structure are summarized in Box 3. I have been using this definition of model for a long time, and I am yet to find a model in any branch of science that cannot be expressed in these terms.

Models are of many kinds, depending on their purpose. All models are idealizations, representing only structure that is *relevant* to the purpose, not necessarily including all five types of structure in Box 3. The prototypical kind of model is a map. Its main purpose is to specify geometric structure (relations among places), though it also specifies objects in various locations. Maps can be extended to represent motion of an object by a path on the map. I call such a model a *motion map*. Motion maps should not be confused with *graphs* of motion, though this point is seldom made in physics or math courses. In relativity theory, motion maps and graphs are combined in a single *spacetime map* to represent integrated *spatiotemporal event structure*.

A *mathematical model* represents the structure of a system by quantitative variables of two types: *state variables*, specifying composition, geometry and object properties; *interaction variables*, specifying links among the parts and with the environment [6]. A *process model* represents temporal structure as change of state variables. There are two types. A *descriptive model* represents change by explicit functions of time. A *dynamical model* specifies equations of change determined by interaction laws. *Interaction laws* express interaction variables as functions of state variables.

A *scientific THEORY* is defined by a system of general principles (or **Laws**) specifying a class of state variables, interactions and dynamics (modes of change) [6, 7]. Scientific practice is governed by two kinds of law:

I. <u>Statutes</u>: General Laws defining the domain and structure of a Theory (such as Newton's Laws and Maxwell's equations)

II. Ordinances: Specific laws defining models

(such as Galileo's law of falling bodies and Snell's law) The *content* of a scientific theory is a population of validated models. The statutes of a theory can be validated only indirectly through validation of models. Laws defining state variables are intimately related to *Principles of Measurement* (also called correspondence rules or operational definitions) for assigning measured values to states of a system. A model is *validated to the degree* that measured values (data) match predicted values determined by the model. The class of systems and range of variables that match a given model is called its *domain of validity*. The domain of validity for a theory is the union of the validity domains for its models.



Fig. 3: Three Kinds of Analogy

Empirical observation and measurement determine an *analogy between a given model and its referent* (a system). I call this a *referential analogy*. An *analogy* is defined as a *mapping of structure* from one domain (*source*) to another (*target*). The mapping is always partial, which means that some structure is not mapped. (For alternative views on analogy see [16].) Analogy is ubiquitous in science, but often goes unnoticed. Several different kinds are illustrated in Figs. 3&4.



similar models of wave propagation for light, sound and water and ropes suppress confounding differences, such as the role of an underlying medium. Such differences are still issues in scientific research as well as points of confusion for students.

A *material analogy* relates structure in different material systems or processes; for example, geometric similarity of a real car to a scale model of the car. An important case that often goes unnoticed, because it is so subtle and commonplace, is *material equivalence* of two material objects or systems, whereby they are judged to be the *same or identical*. I call this an *inductive analogy*, because it amounts to matching the objects to the same model (Fig. 4). I submit that this matching process underlies classical *inductive inference*, wherein repeated events are attributed to a single mechanism.

One other analogy deserves mention, because it plays an increasingly central role in science: the *analogy between conceptual models and computer models*. The formalization of mathematics has made it possible to imbed every detail in the structure of conceptual models in computer programs, which, running in simulation mode, can emulate the behavior of material systems with stunning accuracy. More and more, computers carry out the empirical function of matching models to data without human intervention. However there is an essential difference between computer models and conceptual models, which we discuss in the next section.

Considering the multiple, essential roles of analogy just described, I recommend formalizing the concept of analogy in science with the technical term **MORPHISM**. In mathematics a *morphism is a structure-preserving mapping*: Thus the terms *homomorphism* (preserves algebraic structure) and *homeomorphism* (preserves topological structure). Alternative notions of analogy are discussed in [16].

The above characterization of science by Modeling Theory bears on deep epistemological questions long debated by philosophers and scientists. For example:

- In what sense can science claim *objective knowledge* about the material world?
- To what degree is observed structure inherent in the material world and independent of the observer?
- What determines the **structure categories** for conceptual models in Box 3?



In regard to the last question, I submit in line with Lakoff and Johnson [18, 19, 21] that these are *basic categories of cognition grounded in the human sensorymotor system*. This suggests that answers to all epistemological questions depend on our theory of cognition, to which we now turn.

VII. Modeling Structure of Cognition

If cognition in science is an extension of common sense, then the structure of models in science should reflect structure of cognition in general. To follow up this hint I outline a **Modeling Theory of Cognition**. The theory begins with a crucial distinction between mental models and conceptual models (Fig. 5). **Mental models** are private constructions in the mind of an individual. They can be elevated to **conceptual models** by encoding model structure in symbols that activate the individual's mental model and corresponding mental models in other minds. Just as Modeling Theory characterizes science as construction and use of shared *conceptual models*, I propose to characterize cognition as construction and manipulation of private *mental models*.

As already mentioned, the idea that mental models are central to cognition is commonplace in cognitive science. However, it has yet to crystallize into commonly accepted theory, so I cannot claim that other researchers will approve of the way I construe their results as support for Modeling Theory. The most extensive and coherent body of evidence comes from cognitive linguistics, supporting the **revolutionary thesis**: *Language does not refer directly to the world, but rather to mental models and components thereof! Words serve to activate, elaborate or modify mental models, as in comprehension of a narrative.*

This thesis rejects all previous versions of semantics, which located the referents of language outside the mind, in favor of **cognitive semantics**, which locates referents inside the mind. I see the evidence supporting cognitive semantics as overwhelming [17-24], but it must be admitted that some linguists are not convinced, and many research questions remain.

My aim here is to assimilate insights of cognitive linguistics into Modeling Theory and study implications for cognition in science and mathematics. The first step is to sharpen our definition of concept. Inspired by

the notion of '*construction*' in cognitive linguistics [25], I define a *concept* as a {form, meaning} pair represented by a symbol (or symbolic construction), as schematized in Fig. 6. The *meaning* is given by a mental model or schema called a **prototype**, and the *form* is the structure or a substructure of the prototype.



Fig. 6: Concept triad

This is similar to the classical notion that the meaning of a symbol is given by its *intension* and *extension*, but the differences are profound.

For example, the prototype for the concept *right triangle* is a mental

image of a triangle, and its form is a system of relations among its constituent vertices and sides. The concept of *hypotenuse* has the same prototype, but its form is a substructure of the triangle. This kind of substructure selection is called **profiling** in cognitive linguistics. Note that different individuals can agree on the meaning and use of a concept even though their mental images may be different. We say that their mental images are *homologous*.

In my definition of a concept, the form is derived from the prototype. Suppose the opposite. I call that a *formal concept*. That kind of concept is common in science and mathematics. For example the concept of *length* is determined by a system or rules and procedures for measurement that determine the structure of the concept. To understand the concept, each person must embed the structure in a mental model of his own making. Evidently formal concepts can be derived from "informal concepts" by explicating the implicit structure in a prototype. I submit that this process of *explication* plays an important role in both developing and learning mathematics.

Like a percept, a concept is an irreducible whole, with gestalt structure embedded in its prototype. Whereas a percept is activated by sensory input, a concept is activated by symbolic input. Concepts can be combined to make more elaborate concepts, for which I recommend the new term **construct** to indicate that it is composed of irreducible concepts, though its wholeness is typically than the "sum" of its parts.

We can apply the definition of 'concept' to sharpen the notion of 'conceptual model,' which was employed informally in the preceding section. A **conceptual model** *is now defined as a concept (or construct if you will) with the additional stipulation that the structure of its referent be encoded in its representation by a symbolic construction*, or figure, or some other inscription. Like a concept, a conceptual model is characterized by a triad, as depicted in Fig. 7.

To emphasize the main point: the symbols for concepts refer to mental models (or features thereof), which may or may not correspond to actual material objects (as suggested in Fig.7). Though every conceptual model refers to a mental model, the converse is not true. The brain creates all sorts of mental constructions, including mental models, for which there are no words to express. I refer to such constructions as **ideas** or **intuitions**. *Ideas and intuitions are elevated to concepts by creating symbols to represent them!*



Fig. 7: Conceptual model

My definitions of 'concept' and 'conceptual model' have not seen print before, so others may be able to improve them. But I believe they incorporate the essential ideas. The main task remaining is to elaborate the concept of mental model with reference to empirical support for important claims.

The very idea of *mental model* comes from introspection, so that is a good place to start. However, introspection is a notoriously unreliable guide even to our own thinking, partly because most thinking is unconscious processing by the brain. Consequently, like the tip of an iceberg, only part of a mental model is open to direct inspection. Research has developed means to probe more deeply.

Everyone has imagination, the ability to conjure up an image of a situation from a description or memory. What can that tell us about mental models? Some people report images that are picture-like, similar to actual visual images. However, others deny such experience, and blind people are perfectly capable of imagination. Classical research in this domain found support for the view that *mental imagery is*

Box 4: Spatial MENTAL models

- are *schematic*, representing only some features,
- are *structured*, consisting of *elements and relations*.
- Elements are typically *objects* (or reified things).
- **Object** *properties* **are idealized** (points, lines or paths).
- Object models are always *placed in a background*
- (context or frame).
- Individual objects are *modeled separately* from the frame, so they can move around in the frame.

internalized perception, but not without critics.

Barbara Tversky and collaborators [26] have tested the classical view by comparison to mental model alternatives. Among other things, they compared individual accounts of a visual scene generated from narrative with accounts generated from direct observation and found that they are *functionally equivalent*. A crucial difference is that perceptions have a fixed point of view, while mental models allow change in point of view. Furthermore, spatial mental models are more schematic and categorical than images, capturing some features of the object but not all and incorporating information about the world that is not purely perceptual. Major characteristics of spatial mental models are summarized in Box 4. The best fit to data is a **spatial framework model**, where each object has an *egocentric frame* consisting of mental extensions of three body axes.

The general conclusion is that *mental models represent states of the world* as conceived, not perceived. To know a thing is to form a mental model of it. The details in Box 4 are abundantly supported by other lines of research, especially in cognitive linguistics, to which we now turn.

In the preceding section we saw that concepts of *structure and morphism provide the foundation for models and modeling practices in science* (and, later I will claim, for mathematics as well). My purpose here is to link those concepts to the extensive cognitive theory and evidence reviewed by Lakoff and company [17-24], especially to serve as a guide for those who wish to mine the

rich lode of insight in this domain. To that end, I have altered Lakoff's terminology somewhat but I hope not misrepresented his message.

I claim that **all reasoning is inference from structure**, so I seek to identify basic cognitive structures and understand how they generate the rich conceptual structures of science and mathematics. The following major themes are involved:

- Basic concepts are irreducible **cognitive primitives** grounded in sensorymotor experience.
- All other conceptual domains are structured by **metaphorical extension** from the basic domain.
- Cognition is organized by **semantic frames**, which provide background structure for distinct conceptual domains and modeling in **mental spaces**.

Only a brief orientation to each theme can be given here.

Metaphors are morphisms in which structure in the source domain is projected into the target domain to provide it with structure. The process begins with **grounding metaphors**, which project structural primitives from basic concepts. A huge catalog of metaphors has been compiled and analyzed to make a strong case that all higher order cognition is structured in this way.

Semantic frames provide an overall conceptual structure linking systems of related concepts (including the words that express them). In mathematics, the frames may be general conceptual systems such as arithmetic and geometry or subsystems thereof. Everyday cognition is structured by a great variety of frames, such as the classic *restaurant frame* that that provides a context for modeling what happens in a restaurant. A semantic frame for a temporal sequence of events, such as *dining* (ordering, eating and paying for a meal), is called a **script**.

Fauconnier has coined the term **mental spaces** for the arenas in which mental modeling occurs [23, 24]. Especially significant is the concept of **blending**, whereby distinct frames are blended to create a new frame. The description of cognitive processes in such terms is in its infancy but very promising.

As cognitive grounding for science and mathematics, we are most interested in **basic concepts** of **space**, **time and causality**. Their prototypes, usually called *schemas*, provide the primitive structures from which all reasoning is generated. There are two kinds, called *image schemas and aspectual schemas*.

Image schemas provide common structure for spatial concepts and spatial perceptions, thus linking language with spatial perception. The world's languages use a relatively small number of image schemas, but they incorporate spatial concepts in quite different ways — in English mostly with prepositions. Some prepositions, such as *in/out* and *from/to*, express topological concepts, while others, such as *up/down* and *left/right*, express directional concepts.

The schema for each concept is a structured whole or *gestalt*, where in the parts have no significance except in relation to the whole. For example, the *container schema* (Fig. 8) consists of a boundary that separates interior and exterior spaces. The preposition *in* profiles the interior, while *out* profiles the

exterior.

The container schema provides the structure for the general concepts of *containment* and *space* as a container. The alternative notion of space as a set of points (locations) was not invented until the nineteenth century. The contrast between these two concepts of space has generated tension in the



foundations of mathematics that is still not resolved to everyone's satisfaction.

By metaphorical projection, the container schema structures many conceptual domains. In particular, as Lakoff explains at length, the Categories-

are-containers metaphor provides propositional logic with cognitive grounding in the inherent logic of the container schema (illustrated in Fig. 8). More generally, container logic is the logic of *part-whole structure*, which underlies the concepts of set and system (Box 4).



Aspectual schemas structure events and actions. The prototypical *aspectual concept* is the *verb*, of which the reader knows many examples. The most fundamental aspectual schema is the basic *schema for motion* (Fig. 9), called the **Source-Path-Goal schema** by linguists, who use *trajector* as the default term for any object moving along a path. This schema has its own logic, and provides cognitive structure for the concepts of *continuity* and *linear order* in mathematics. Indeed, Newton conceived of curves as traced out by moving points, and his First Law of Motion provides grounding for the concept of time on the more basic concept of motion [7]. Indeed, the Greek concept of a curve as a *locus* of points suggests the action of drawing the curve. In physics the concept of motion is integrated with concept of space, and the geometry of motion is called *kinematics*.

Though the path schema of Fig. 9 is classified as aspectual in cognitive linguistics, evidence from cognitive neuroscience and perceptual psychology suggests that it should regarded as an image schema. It is a mistake to think that visual processing is limited to static images. In visual cortex motion is processed concurrently with form. Even young children can trace the path of a thrown ball, and the path is retained mentally as a kind of afterimage, though, like most of visual processing, it remains below the radar of consciousness.

Clearly, the basic concepts of structure and quantity come from geometry. Evidently the *general concept of structure* is derived from geometry by metaphorical projection to practically every conceptual domain. An obvious example is the general concept of *state space*, where states are identified with locations.

Categories are fundamental to human thought, as they enable distinctions between objects and events. One of the pillars of cognitive linguistics is Eleanor Rosch's discovery that *Natural Categories* are determined by mental prototypes. This should be contrasted with the classical concept of a *Formal Category* for which membership is determined by a set of defining properties, a noteworthy generalization of the container metaphor. The notion of categories as containers cannot account for a mountain of empirical evidence on natural language use.

Natural categories (commonly called *Radial categories*) are discussed at great length by Lakoff [18], so there is no need for details here. The term "radial" expresses the fact that natural categories have a radial structure of subordinate and superordinate categories with a central category for which membership is determined by matching to a prototype. The matching process accounts for fuzziness in category boundaries and graded category structure with membership determined by partial matching qualified by *hedges*, such as "It looks like a bird, but . . ."

The upshot is that the structure of natural categories is derived from prototypes whereas for formal categories structure is imposed by conventions. As already noted for formal concepts, formal categories play an essential role in creating objective knowledge in science and mathematics. However, the role of radial categories in structuring scientific knowledge has received little notice [27].

Most human reasoning is inference from mental models. We can distinguish several types of **model-based reasoning**:

- **Abductive,** to complete or extend a model, often guided by a semantic frame in which the model is embedded.
- **Deductive**, to extract substructure from a model.
- Inductive, to match models to experience.
- Analogical, to interpret or compare models.
- Metaphorical, to infuse structure into a model.
- **Synthesis,** to construct a model, perhaps by analogy or blending other models.
- Analysis, to profile or elaborate implicit structure in a model.

Justification of model-based reasoning requires translation from mental models to *inference from conceptual models* that can be publicly shared, like the scientific models in the preceding section.

In contrast, **formal reasoning** is computational, using axioms, production rules and other procedures. It is the foundation for rigorous proof in mathematics and formal logic. However, I daresay that mathematicians and even logicians reason mostly from mental models. Model-based reasoning is more general and powerful than propositional logic, as it integrates multiple representations of information (propositions, maps, diagrams, equations) into a coherently structured mental model. Rules and procedures are central to the formal concept of inference, but they can be understood as prescriptions for operations on mental models as well as on symbols.

We have seen how Modeling Theory provides a theoretical framework for cognitive science that embraces the findings of cognitive linguistics. Thus it provides the means for scientific answers to long-standing philosophical questions, such as: What is the role of language in cognition? Is it merely an expression of thought and a vehicle for communication? Or does it determine the structure of thought? As for most deep philosophical questions, the answer is "Yes and no!" Yes, the basic structure in thought is grounded in the evolved structure of the sensory-motor system. No, there is more to the story. The structure of mental models, perhaps even of aspectual and image schemas, is shaped by experience with tools, linguistic as well as physical. In the following sections we consider evidence for this in physics and mathematics.

VIII. Concepts of Force in science and common sense

From the beginning, Modeling Theory was developed with an eye to improving instruction in science and mathematics, so we look to that domain for validation of the theory. In section II, I reported the stunning success of Malcolm Wells' initial experiment with Modeling Theory and its subsequent flowering in the Modeling Instruction Project. My purpose in this section is, first to describe what Modeling Theory initially contributed to that success, and second to propose new explanations based on the current version of the theory. This opens up many opportunities for further research.

School physics has a reputation for being impossibly difficult. The rap is that few have the talent to understand it. However, PER has arrived at a different explanation by investigating *common sense* (CS) concepts of force and motion in comparison to the Newtonian concepts of physics. The following conclusions are now widely accepted:

- CS concepts dominate student thinking in introductory physics!
- Conventional instruction is almost totally **ineffective** in altering them!
- This result is **independent** of the instructor's academic qualifications, teaching experience, and (unless informed by PER) mode of teaching!

Definitive quantitative support for these claims was made possible by development of the *Force Concept Inventory* (FCI). The initial results [3, 5] have been repeatedly replicated (throughout the U.S. and elsewhere), so the conclusions are universal, and only the ill-informed are skeptical.

The implications for conventional instruction could hardly be more serious! Student thinking is far from Newtonian when they begin physics, and it has hardly changed (<15%) when they finish the first course. Consequently, students systematically misinterpret almost everything they read, hear and see throughout the course. Evidence for this catastrophe has always been there for teachers to see, but they lacked the conceptual framework to recognize it. Witness the common student complaint: "I understand the theory, I just can't work the problems!" In my early years of teaching I dismissed such claims as unfounded, because ability to work problems was regarded as the definitive test of understanding. Now I see that the student was right. He did understand the theory — but it was the wrong theory! His theory wrapped up his CS concepts in Newtonian words; he had learned *jargon* instead of Newtonian concepts.

Since students are oblivious to the underlying conceptual mismatch, they cannot process their own mistakes in problem solving. Consequently, they resort to rote learning and depend on the teacher for answers. A sure sign of this state of affairs in a physics classroom is student clamoring for the teacher to demonstrate solving more and more problems. They confuse memorizing problem solutions with learning how to solve problems. This works to a degree, but repeated failure leads to frustration and humiliation, self-doubt and ultimately student turn-off!

Happily, this is not the end of the story. Figure 10 summarizes data from a nationwide sample of 7500 high school physics students involved in the *Modeling Instruction Project* during 1995–98. The mean FCI pretest score is about 26%, slightly above the random guessing level of 20%, and well below the 60% score which, for empirical reasons, can be regarded as a *threshold* in the understanding of Newtonian mechanics.

Figure 10 shows that traditional high school instruction (lecture, demonstration, and standard laboratory activities) has little impact on student beliefs, with an average FCI posttest score of 42%, still well below the Newtonian threshold. This is data from the classes of teachers before participating in the Modeling Instruction Project.

Participating teachers attend an intensive 3-week Modeling Workshop that immerses them in modeling pedagogy and acquaints them with curriculum materials designed expressly to support it. Almost every teacher enthusiastically adopts the approach and begins teaching with it immediately. After their first year of teaching posttest scores for students of these *novice modelers* are about 10% higher, as shown in Fig. 10 for 3394 students of 66 teachers. Students of expert modelers do much better.

For 11 teachers identified as expert modelers after two years in the Project, posttest scores of their 647 students averaged 69%. *Their average gain is more than two standard deviations higher than the gain under traditional instruction*. It is comparable to the gain achieved by the first expert modeler Malcolm Wells.

The 29%/69% pretest/posttest means for the expert modelers should be compared with the 52%/63% means for calculus-based physics at a major university [5]. We now have many examples of modelers who consistently achieve posttest means from 80-90%. On the other hand, even initially underprepared teachers eventually achieve substantial gains, comparable to gains for well-prepared teachers after two years in the project. FCI scores are vastly more informative than scores for an ordinary test. To see why, one needs to examine the structure of the test and the significance of the questions. The questions are based on a detailed taxonomy of *common sense* (CS) *concepts of force and motion* derived from



research. The taxonomy is structured by a systematic analysis of the Newtonian force concept into six fundamental conceptual dimensions. Each question requires a forced choice between a Newtonian concept and CS alternatives for best explanation in a common physical situation, and the set of questions systematically probes all dimensions of the force concept. Questions are designed to be meaningful to readers without formal training in physics.

To a physicist the correct choice for each question is so obvious that the whole test looks trivial. On the other hand, virtually all CS concepts about force and motion are incompatible with Newtonian theory. Consequently, every missed question has high information content. Each miss is a sure indicator of non-Newtonian thinking, as any skeptical teacher can verify by interviewing the student who missed it.

Considering the FCI's comprehensive coverage of crucial concepts, the abysmal FCI scores for traditional instruction imply *catastrophic failure to penetrate student thinking!* Most high school students and half the university students do not even reach the Newtonian threshold of 60%. Below that threshold students have not learned enough about Newtonian concepts to use them reliably in reasoning. No wonder they do so poorly on problem solving.

Why is traditional instruction so ineffective? Research has made the answer clear. To cope with ordinary experience each of us has developed a loosely organized system of intuitions about how the world works. That provides intuitive grounding for CS beliefs about force and motion, which are embedded in natural language and studied in linguistics and PER. Research shows that CS beliefs are **universal** in the sense that they are much the same for everyone, though there is some variation among individuals and cultures. They are also very **robust** and expressed with confidence as obvious truths about experience.

Paradoxically, physicists regard most CS beliefs about force and motion as obviously false. From the viewpoint of Newtonian theory they are simply *misconceptions* about the way the world truly is! However, it is more accurate, as well as more respectful, to regard them as *alternative hypotheses*. Indeed, in preNewtonian times the primary CS "misconceptions" were clearly articulated and forcefully defended by great intellectuals — Aristotle, Jean Buridan, Galileo, and even Newton himself (before writing the *Principia*) [4]. Here we see another side of the paradox:

To most physicists today Newtonian physics describes obvious structure in perceptible experience, in stark contrast to the subtle quantum view of the world. I have yet to meet a single physicist who recollects ever holding prescientific CS beliefs, though occasionally one recalls a sudden *aha!* insight into Newton's Laws. This *collective retrograde amnesia* testifies to an important fact about memory and cognition: recollections are reconstructed to fit current cognitive structures. Thus, physicists cannot recall earlier CS thinking because it is filtered by current Newtonian concepts.

In conclusion, the crux of the problem with traditional instruction is that it does not even recognize CS beliefs as legitimate, let alone address them with argument and evidence. In contrast, *Modeling Instruction* is deliberately designed to address this problem with

- *Modeling activities* that systematically engage students in developing models and providing their own explanations for basic physical phenomena,
- *Modeling discourse* (centered on visual representations of the models) to engage students in articulating their explanations and comparing them with Newtonian concepts,
- *Modeling concepts and tools* (such as graphs, diagrams and equations) to help students simplify and clarify their models and explanations.

Instructors are equipped with a taxonomy of CS concepts to help recognize opportunities to elicit the concepts from students for comparison with Newtonian alternatives and confrontation with empirical evidence. Instructors know that students must recognize and resolve discrepancies by themselves. Telling them answers does not work.

From years of experimenting with modeling discourse (especially in the classroom of Malcolm Wells) we have learned to focus on the *three CS concepts* listed in Box 5. When these concepts are adequately addressed, other misconceptions in our extensive taxonomy [5]

Box 5 Contrasting Force Concepts								
Newtonian	VS.	Common Sense	Posttest Discrepancy					
• First Law	\Leftrightarrow	"Motion requires force (Impetus Principle)	~ 60%					
• Second Law	\Leftrightarrow	"Force is action" (No Passive forces)	$\sim 40\%$					
• Third Law	\Leftrightarrow	"Force is war" (Dominance Principle	~ 90%)					

tend to fall away automatically. Their robustness is indicated by the posttest discrepancies (Box 5) from FCI data on more than a thousand university students. After completing a first course in calculus-based physics, the fraction

of students choosing CS alternatives over Newton's First, Second and Third Laws was 60%, 40% and 90% respectively. Of course, Newton's Laws are not named as such in the FCI. 80% of the students had already taken high school physics and could state Newton's Laws as slogans before beginning university physics.

After the Modeling Instruction Project was up and running, I learned about Lakoff's work on metaphors and its relevance for understanding CS force and motion concepts. I presented the ideas to teachers in Modeling Workshops but have no evidence that this improved the pedagogy, which was already well developed. I suppose that much of the new insight was overlooked, because it was not nailed down in print, so let me record some of it here as analysis of the three *primary CS concepts* in Box 5.

The Impetus Principle employs the Object-As-Container metaphor, where the container is filled with impetus that makes it move. After a while the impetus is used up and the motion stops. Of course, students don't know the term *impetus* (which was coined in the middle ages); they often use the term *energy* instead. Naïve students don't discriminate between energy and force. Like Newton himself before the *Principia*, they have to be convinced that "free particle motion in a straight line" is a natural state that doesn't require a motive force (or energy) to sustain it. This does not require discarding the impetus intuition (which is permanently grounded in the sensory-motor system in any case) but realigning the intuition with physics concepts of inertia and momentum.

The **CS** prototype for force is human action on an object. Consequently, students don't recognize constraints on motion like walls and floors as due to contact forces. "They just get in the way." Teachers try to activate student intuition by emphasizing that "force is a push or a pull," without realizing that unqualified application of this metaphor excludes passive forces. Besides, no textbooks explicitly note that **universality of force** is an implicit assumption in Newtonian theory, which requires that motion is influenced only by forces. To arrive at force universality on their own, students need to develop intuition to recognize forces in any instance of physical contact. As an instructional strategy to achieve that end, Clement and Camp [28] engage students in constructing a series of "bridging analogies" to link, for example, the unproblematic case of a person pressing on a spring to the problematic case of a book resting on a table. I recommend modifying their approach to include a common vector representation of normal force in each case to codify symbolic equivalence (as in Fig. 4).

In situations involving Newton's Third Law, the slogan "for every action there is an equal and opposite reaction" evokes a misplaced analogy with a struggle between "opposing forces," from which it follows that one must be the winner, "overcoming" the other, in contradiction to the Third Law. The difficulty that students have in resolving this paradox is reflected in the fact that FCI questions on the Third Law are typically the last to be mastered. DiSessa [29] gives a perceptive analysis of Third Law difficulties and measures to address them. Such insights into student thinking as just described are insufficient for promoting a transition to Newtonian thinking in the classroom. The literature is replete with attempts to address specific misconceptions with partial success at best. So what accounts for the singular success of Modeling Instruction as measured by the FCI (Fig. 10)? As for any expert performance, detailed planning and preparation is essential for superior classroom instruction. (The intensive Modeling Workshops help teachers with that.) However, Modeling Instruction is unique in its strategic design.

Rather than address student misconceptions directly, Modeling Instruction creates an environment of activities and discourse to stimulate reflective thinking about physical phenomena that are likely to evoke those misconceptions. The environment is structured by an emphasis on models and modeling with multiple representations (maps, graphs, diagrams, equations). This provides students with conceptual tools to sharpen their thinking and gives them access to Newtonian concepts. In this environment students are able to adjust their thinking to resolve discrepancies within the Newtonian system, which gradually becomes their own. Rather than learning Newtonian concepts piecemeal, they learn them as part of a coherent Newtonian system. Construction of a Newtonian model requires coordinated use of all the Newtonian concepts, and only this reveals the coherence of the Newtonian system. That coherence is not at all obvious from the standard statement of Newton's Laws. I believe that learning Newtonian concepts as a coherent system best accounts for high FCI scores. Logically this is only a sufficient condition for a high score, but I estimate that a high score from piecemeal understanding of Newtonian physics is improbably low. Thus, it is best to interpret overall FCI score as a measure of coherence in understanding Newtonian physics.

One other important point deserves mention here. As we have noted, Modeling Theory informed by empirical evidence from cognitive science holds that mental models are always constructed within a semantic frame. Accordingly, I suppose that physical situations (regardless of how they are presented) activate a Newtonian semantic frame in the mental spaces of physicists. And I submit that physics instruction is not truly successful until the same is true for students. It is well known that students tend to leave the science they have learned in the classroom and revert to CS thinking in every day affairs. Perhaps recognizing this as a problem of semantic framing can lead to a better result.

As I have described it, Modeling Instruction does not depend on detailed understanding of how students think. Indeed, I have tried to steer it clear of doubtful assumptions about cognition that might interfere with learning. However, I now believe that advances in the Modeling Theory of cognition described in Section VII are sufficient to serve as a reliable guide for research to further improve instruction by incorporating details about cognition. Let me sketch the prospects with specific reference to force and motion concepts.

The intertwined concepts of *force and causation* have been studied extensively in cognitive linguistics. Lakoff and Johnson [19] show that the great

variety of causal concepts fall naturally into a radial category ("kinds of causation") structured by a system of metaphorical projections. The central prototype in this category is given by the Force-as-Human-Action metaphor, in agreement with our analysis above. Their analysis provides an organizational framework for the whole body of linguistic research on causation. That research provides valuable insight into CS concepts of force and motion that deserves careful study. However, limited as it is to study of natural languages, linguistic research does not discover the profound difference in the force concept of physicists. For that we need to turn to PER, where the deepest and most thorough research is by Andy diSessa [29].

In much the same way that linguists have amassed evidence for the existence of prototypes and image schemas, diSessa has used interview techniques to isolate and characterize conceptual primitives employed by students in causal reasoning. He has identified a family of irreducible "knowledge structures" that he calls *phenomenological primitives* or **p-prims**. Since diSessa's definitive monograph on p-prims in 1993, converging evidence from cognitive linguistics has made it increasingly clear that his p-prims are of the same ilk as the image and aspectual schemas discussed in the preceding section. Accordingly, I aim to integrate them under the umbrella of Modeling Theory.

Let us begin with the most important example, which diSessa calls Ohm's p-prim. As he explains,

Ohm's p-prim comprises "an <u>agent</u> that is the locus of an <u>impetus</u> that acts against a <u>resistance</u> to produce a <u>result</u>."

Evidently this intuitive structure is abstracted from experience pushing objects. It is an important elaboration of the central Force-as-Action metaphor mentioned above — *Very important!* — Because this structure is fundamental to qualitative reasoning. The logic of Ohm's p-prim is the *qualitative proportion*:

more effort \Rightarrow more result,

and the *inverse proportion*:

more resistance \Rightarrow less result.

This reasoning structure is evoked for explanatory purposes in circumstances determined by experience.

DiSessa identifies a number of other p-prims and catalogs them into a cluster that corresponds closely to the taxonomy of CS force and motion concepts used to construct the FCI. His monograph should be consulted for many details and insights that need not be repeated here. Instead, I comment on general aspects of his analysis.

In accord with Lakoff and Johnson, diSessa holds that causal cognition is grounded in a loosely organized system of many simple schemas derived from sensory-motor experience. P-prims provide the grounding for our intuitive sense of (causal) mechanism. They are the CS equivalent of physical laws, used to explain but not explainable. To naïve subjects, "that's the way things are." As to be expected from their presumed origin in experience, p-prims are cued directly by situations without reliance on language. DiSessa asserts that pprims are inarticulate, in the sense that they are not strongly coupled to language. Here there is need for further research on subtle coupling with language that diSessa has not noticed. For example, Lakoff notes that the preposition *on* activates and profiles schemas for the concepts of *contact* and *support*, which surely should be counted among the p-prims.

As disclosed in Ohm's p-prim, the concept of (causal) **agency** entails a basic

Causal syntax: agent \rightarrow (kind of action) \rightarrow on patient \rightarrow result.

DiSessa notes that this provides an interpretative framework for $\mathbf{F} = m\mathbf{a}$, and he recommends exploiting it in teaching mechanics. However he does not recognize it as a basic aspectual schema for verb structure, which has been studied at length in cognitive grammar [22]. Aspectual concepts are generally about event structure, where events are changes of state and causes (or causal agents) induce events. Causes cannot be separated from events. Here is more opportunity for research.

Under physics instruction, diSessa says that p-prims are refined but not replaced, that they are gradually tuned to expertise in physics. Considering the role of metaphor and analogy in this process, it might be better to say that pprims are realigned. There are many other issues to investigate in this domain. Broadly speaking, I believe that we now have sufficient theoretical resources to guide research on instructional designs that target student p-prims more directly to retune and integrate them into schemas for more expert-like concepts. I propose that we design *idealized expert prototypes* for force and motion concepts to serve as targets for instruction. This would involve a more targeted role for diagrams to incorporate figural schemas into the prototypes.

The call to design expert prototypes embroils us in many deep questions about physics and epistemology. For example, do forces really exist outside our mental models? We have seen that Modeling Theory tells us that the answer depends on our choice of theoretical primitives and measurement conventions. Indeed, if momentum is a primitive, then Newton's Second Law is reduced to a definition of *force as momentum flux* and the Third Law expresses momentum conservation. The physical intuition engaged when mechanics is reformulated in terms of momentum and momentum flux has been investigated by diSessa among others, but few physicists have noted that fundamental epistemological issues are involved. Not the least of these issues is the transition from classical to quantum mechanics, where momentum is king and force is reduced to a figure of speech.

A related epistemological question: Is causal knowledge domainspecific? Causal claims are supported by causal inference from models based on acquired domain-specific knowledge. But to what degree does inference in different domains engage common intuitive mechanisms? Perhaps the difference across domains is due more to structure of the models rather than the reasoning. Perhaps we should follow Lakoff's lead to develop *force and* *interaction* as a radial category for a progression of interaction concepts ranging from particles to fields.

I am often asked how the FCI might be emulated to assess student understanding in domains outside of mechanics, such as electrodynamics, thermodynamics, quantum mechanics and even mathematics. Indeed, many have tried to do it themselves, but the result has invariably been something like an ordinary subject matter test. The reason for failure is insufficient attention to cognitive facts and theory that went into FCI design, which I now hope are more fully elucidated by Modeling Theory. The primary mistake is to think that the FCI is basically about detecting misconceptions in mechanics. Rather, as we have seen, it is about comparing CS causal concepts to Newtonian concepts. The p-prims and image schemas underlying the CS concepts are not peculiar to mechanics, they are basic cognitive structures for reasoning in any domain. Therefore, the primary problem is to investigate how these structures are adapted to other domains. Then we can see whether reasoning in those domains requires other p-prims that have been overlooked. Finally, we can investigate whether and how new p-prims are created for advanced reasoning in science and mathematics. That brings us to the next section, where we discuss the development of conceptual tools to enhance scientific thinking.

IX. Tools to think with

The evolution of science is driven by invention and use of tools of increasing sophistication and power! The tools are of two kinds: instruments for detecting patterns in the material world, and symbolic systems to represent those patterns for contemplation. As outlined in Fig. 11, we can distinguish three major stages in tool development.

In the perceptual domain, pattern detection began with direct observation using human sensory apparatus. Then the perceptual range was extended by scientific instruments such as telescopes and microscopes. Finally, human sensory detectors are replaced by more sensitive detection instruments, and the data are processed by computers with no role for humans except to interpret the final results; even there the results may be fed to a robot to take action with no human participation at all.

Tool development in the cognitive domain began with the natural languages in spoken and then written form. Considering their *ad hoc* evolution, the coherence, flexibility and subtlety of the natural languages is truly astounding. More deliberate and systematic development of symbolic tools came with the emergence of science and mathematics. The next stage of enhancing human cognitive powers with computer tools is just beginning. My purpose in this section is to discuss what Modeling Theory can tell us about the intuitive foundations of mathematics to serve as a guide for research on design of better instruction and better mathematical tools for modeling in science and engineering.



While science is a search for structure, mathematics is the science of structure. Every science develops specialized modeling tools to represent the structure it investigates. Witness the rich system of diagrams that chemists have developed to characterize atomic and molecular structure. Ultimately, though, these diagrams provide grist for mathematical models of greater explanatory power. What accounts for the ubiquitous applicability of mathematics to science?

I have long wondered how mathematical thinking relates to theoretical physics. According to Modeling Theory, theoretical physics is about designing and analyzing conceptual models that represent structure in the material world. For the most part these models are mathematical models, so the cognitive activity is called mathematical modeling. But how does mathematical thinking differ from the mathematical modeling in physics? Can it be essentially the same when there are no physical referents for the mathematical structures? *I am now convinced that the answer is yes*! The light went on when I learned about cognitive semantics and realized that **the referents for cognition in both mathematics and physics are mental models!** Lakoff and Núñez [20] argue forcefully for the same conclusion, but I want to put my own twist on it.

I contend that the basic difference between mathematics and physics is how they relate their mental models to the external world. Physicists aim to match their mental models to structure in the material world. I call the ability to make such matches **physical intuition.** Note that mathematics is not necessarily involved in this. In contrast, mathematicians aim to match their mental models to structure in symbolic systems. I call the ability to make such matches **mathematical intuition**. To be sure, physicists also relate their mental models to mathematical structures, but for the most part they take the mathematics as given. When they do venture to modify or extend the mathematical structures they function as mathematicians. Indeed, that is not uncommon; a vast portion of mathematics was created by theoretical physicists.

According to Modeling Theory, mathematicians work with intuitive structures (grounded in sensory-motor experience) that every normal person has. They proceed to encode these structures in symbolic systems and elaborate them using the intuitive inferential structures of p-prims and image schemas. I submit that mathematical thinking involves a feedback loop generating external symbolic structures that stimulate modeling in mental spaces to generate more symbolic structure. Though some mathematical thinking can be done with internal representations of the symbols, external representation is essential for communication and consensus building [30]. For this reason, I believe that the invention of written language was an essential prerequisite to the creation of mathematics.

Let's consider an example of intuitive grounding for mathematical structures. Lakoff and Núñez [20] give many others, including four grounding metaphors for arithmetic. Note that the intuitive causal syntax discussed in the previous section can be construed (by metaphorical projection at least) as

Operator syntax: agent \rightarrow (kind of action) \rightarrow on patient \rightarrow result,

where the action is on symbols (instead of material objects) to produce other symbols. Surely this provides an intuitive base for the mathematical concept of function (though it may not be the only one). Exploration of mental models reveals various kinds of structure that can be encoded and organized into symbolic systems such as Set theory, Geometry, Topology, Algebra and Group theory. Note that the number of distinct types of mathematical structure is limited, which presumably reflects constraints on their grounding in the sensory-motor system. Of course, to confirm this point of view thorough research is needed to detail the intuitive base for each type of mathematical structure. Lakoff and Núñez [20] have already made a good start.

The upshot is that cognitive processes in theoretical physics and mathematics are fundamentally the same, centered on construction and analysis of conceptual models. Semantics plays a far more significant role in mathematical thinking (and human reasoning in general) than commonly recognized — it is the *cognitive semantics* of mental models, mostly residing in the cognitive unconscious, but often manifested in pattern recognition and construction skills [31]. Mathematical intuition (like physical intuition) is a repertoire of mental structures (schemas) for making and manipulating mental models! This goes a long way toward answering the question: What does it mean to *understand* a scientific concept? I am not alone in my opinion on the intimate relation between physics and mathematics. Here is a brief extract from a long diatribe *On Teaching Mathematics* by the distinguished Russian mathematician V. I. Arnold [32]:

"Mathematics is a part of physics. Physics is an experimental science, a part of natural science. Mathematics is the part of physics where experiments are cheap. . . . In the middle of the 20th century it was attempted to divide physics and mathematics. The consequences turned out to be catastrophic. Whole generations of mathematicians grew up without knowing half of their science and, of course in total ignorance of other sciences."

Arnold is deliberately provocative but not flippant. He raises a very important educational issue that deserves mention quite apart from the deep connection to cognitive science that most concerns us here.

There is abundant evidence to support Arnold's claim. For example, up until World War II physics was a required minor for mathematics majors in US universities. Since it was dropped, the mathematics curriculum has become increasingly irrelevant to physics majors, and physics departments provide most of the mathematics their students need. At the same time, mathematicians have contributed less and less to physics, with some exceptions like the Russian tradition that Arnold comes from, which has sustained a connection to physics. But the most serious consequence of the divorce of mathematics from physics is the fact that, in the U.S. at least, most high school math teachers have little insight into relations of math they teach to science in general and physics in particular. Here is a bit of data to support my contention: We administered the FCI to a cohort of some 20 experienced high school math teachers. The profile of scores was the same as the pitiful profile for traditional instruction in Fig. 10, with the highest score at the Newtonian threshold of 60%. Half the teachers missed basic questions about relating data on motion to concepts of velocity and acceleration. This chasm between math and science, now fully ensconced in the teachers, may be the single most serious barrier to significant secondary science education reform.

To document deficiencies in math education, many have called for a *Math Concept Inventory* (MCI) analogous to the FCI. I have resisted that call for lack of adequate theory and data on intuitive foundations for mathematical thinking. There is lots of educational research on conceptual learning in mathematics, but most of it suffers from outdated cognitive theory. Modeling Theory offers a new approach that can profit immediately from what has been learned about cognitive mechanisms in physics. We need to identify **"m-prims"** that are mathematical analogs of the p-prims discussed in the preceding section. I suspect that underlying intuitive mechanisms are the same for m-prims and p-prims, but their connections to experience must be different to account for the difference between mathematical and physical intuition noted above. I recommend coordinated research on m-prims and p-prims aiming for a comprehensive Modeling Theory of cognition in science and mathematics.

I have barely set the stage for application of Modeling Theory for my favorite enterprise, namely, the design of modeling tools for learning and doing science, engineering and mathematics [10]. I have previously described the

influence of my Geometric Algebra research on development of Modeling Theory [13]. Now I believe that Modeling Theory has matured to the point where it can contribute, along with Geometric Algebra, to the design of more powerful modeling tools, especially tools embedded in computer software. But that is a task for tomorrow!

X. Conclusion

Central thesis: Cognition in science, mathematics, and everyday life is basically about making and manipulating *mental models*.

• The human cognitive capacity for creating, manipulating and remembering *mental models* has evolved to facilitate coping with the environment, so it is central to "common sense" thinking and communication by humans.

• Human culture has expanded and augmented this capacity by creating *semiotic systems*: representational systems of signs (symbols, diagrams, tokens, icons, etc.), most notably spoken and written language.

• Science and mathematics has further extended the use of symbolic systems deliberately and self-consciously, but the *cognitive mechanisms involved are essentially the same as for common sense*.

Scientific modeling is a "deliberate and self-conscious extension of the evolved cognitive capabilities for "mapping" the environment." (Giere)

Science is a refinement of common sense! differing in respect to:

Objectivity – based on explicit rules & conventions for observerindependent inferences

Precision – in measurement – in description and analysis
Formalization – for mathematical modeling and analysis of complex systems
Systematicity – coherent, consistent & maximally integrated bodies of knowledge
Reliability – critically tested & reproducible results
Skepticism – about unsubstantiated claims
Knowledge and Wonder – so say Weisskopf & Sagan
Social structure and norms – Ziman

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Embedding Modeling in the General Physics Course: Rationale & Tools

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Abstract

Computers are increasingly shaping new science learning environments where learning science is closer to doing science. The language of mathematical modeling (variables, quantities, functions, vectors, change, rates of change, accumulation, etc.) can be implemented in different types of computer software but some tools, like the so-called "system dynamics tools", can confuse physics educators about the nature and language of modeling. This paper argues that computer tools, with the explicit use of algebraic, iterative and differential equations, combined with the explicit teaching of simple numerical methods, give a better context for embedding mathematical modeling in the physics curriculum, particularly workshop and activity-based curricula.

Computers and learning environments

It is more than two decades since computers have become ubiquitous tools in science and engineering for measuring, computing, experiencing, modeling, publishing, etc. Science and engineering educators are aware that the way science is taught and learnt should be as close as possible the way science is done. This is relatively easy to recognize but is more difficult to implement. There is a worldwide effort to change but the change will probably be slower than most leaders expect: history of education has shown that change is a very complex and slow process. The directions of change can be summarized as: (1) meaningful learning is an active process of the learner, not necessarily a consequence of good teaching; (2) learning is both an individual process and a social and shared process, involving peers and mentors; (3) students can be active learners in lectures, not only in laboratory work; (4) previous knowledge and common sense ideas interfere with new knowledge and must be addressed explicitly; and (5) students must use computers as science professionals do.

Besides these directions of change, other issues related to the inherent characteristics of computer environments, can be raised. E.g., proper software: (1) allows the exploration of the meaning of models and mathematical ideas without tedious computations; (2) facilitates the reification of mathematical objects as tools to think with, making them concrete-abstract objects; and (3) permits the simultaneous manipulation of multiple representations of mathematical models and ideas. There is also another relevant characteristic of computer environments in science

learning: contrary to paper and pencil, computers allow knowledge to be *performative* in a non rhetorical sense. For example, solving problems can be an interactive activity with computer models, not just a paper and pencil sequence of equations and computations.

"We shape our classrooms and afterwards our classrooms shape us"

In 1944 Winston Churchill said about the reconstruction of the Houses of Parliament that "We shape our buildings, and afterwards our buildings shape us". A similar statement can be made about learning places, such as schools and colleges. If we want active learning settings in schools, the shape of learning places must be consistent with active learning, not with reception learning. This important issue has been raised recently by a group of scientists and science educators in the journal *Science* (Handelsman *et al.*, 2005): the "manifesto" they present can be a powerful document to help change in science education, not only in universities but also in high schools.

The language of mathematical modeling and computer tools

Since Galileo, Mathematics has been the language of the physical sciences. This language is at the root of the success of science and technology since it allows complex phenomena to be described using simple symbols and concepts, which can be used to provide accurate predictions.

Table 1 shows the basic elements of the language of mathematical modeling of physical phenomena (Bais, 2005).

variables		
dependent and independent		
domain and codomain		
quantities (and metrics!)		
functions and equations		
constants and parameters		
vectors		
change		
rates of change		
iterations		
accumulation		
differential equations		
initial conditions		
graphs		
trajectories		

Table 1:	Basic	elements	of the	language	of mathemat	ical modeling
10000 11	200000	01011101115	<i>oj</i>		<i>oj</i>	

Let me illustrate how these elements can be used with two modeling tools: a spreadsheet (Excel or similar) and Modellus (Teodoro, 2002).

Modeling with Excel

Microsoft Excel is the most common spreadsheet. Figure 1 shows an Excel model that illustrates how a change in velocity, defined by a magnitude and an angle, can be used to describe the motion of an object (e.g., a boat).



Figure 1: Modeling the motion of a boat with Excel using iterative equations (new position is computed from previous position plus change).

Some characteristics of this Excel model are:

- time, speed and angle with north are independent variables;
- time has a domain of [0, 20] s and step of 1 second;
- velocity components are functions of speed and angle with north (this angle is usually called an azimuth in navigation);
- time step is a parameter (i.e., an independent variable that usually is held constant);
- velocity and position are vectors, since they are described by two numbers;
- position vector has an initial value;
- each velocity component is used to compute the next position in the respective component;
- time and position components are computed with iterations (new value = old value + change);
- change in each position component is computed by rate of change × time step;

- each position component is accumulating change and so the position vector is also accumulating change;
- trajectory is shown using the scatter graph tool, with equal scales in each variable;
- position coordinates are graphed as functions of time, in its domain;

Modeling with Modellus

Modellus (Teodoro, 2002) is a mathematical modeling tool freely available on the Internet in six languages. It has been used in mathematics and physics curricula in different countries and it is considered an integral part of the Advancing Physics curriculum in the UK (Ogborn & Whitehouse, 2000, 2001). Modellus has a user interface that allows students to start doing meaningful conceptual and empirical experiments almost without the need to learn new syntax, unlike most other modeling tools. The different steps in the process of constructing and exploring models can be done with Modellus, both from the physical point of view and from the mathematical point of view. Mathematical models are treated as concrete-abstract objects: concrete in the sense that they can be manipulated directly with a computer and abstract in the sense that they are representations of relations between variables (for an introduction to Modellus, see Teodoro, 2004).

Let's now look at a similar model of the above Excel model using Modellus.



Figure 2: Modeling the motion of a boat with Modellus. The magnitude and the direction of the velocity of the boat are controlled with the mouse.

In this Modellus model:

(1) time and velocity are independent variables;

- (2) time has a domain of [0, 20] s and step of 0.1 seconds (this is smaller than in the Excel model just because of the need to have the model running approximately in real time);
- (3) time step is a parameter, as well as initial velocity components (these components are changed with the mouse, manipulating the velocity vector in the Animation Window);
- (4) velocity and position are vectors;
- (5) position vector has an initial value;
- (6) change in each position component is computed with iterations (new value = old value + rate of change × time step);
- (7) each position component is accumulating change and so the position vector is also accumulating change;
- (8) trajectory is shown using in Animation Window;
- (9) position coordinates are graphed as functions of time, in its domain, in the Graph Window.

Tools for modeling

It has been illustrated above how the language of modeling can be implemented using two different computer modeling tools: a spreadsheet and an equation based modeling tool. In the last three decades, many types of software have been used or developed to implement the language of mathematical modeling in the physics curricula of schools and undergraduate studies. The first reference I found was a MSc thesis written by J. K. Atkin (1975) where the author describes how a simple programming language can be used for learning mathematical modeling1. This approach has since then been used by many other physics educators. with professional languages like Pascal (Redish & Wilson, 1993) and educational languages like Logo (Hurley, 1985). There are still communities of educators and researchers using the "programming approach" but with more powerful computer languages (e.g., NetLogo), with scripting (e.g., Physlets) or with specific modeling environments with direct manipulation of visual interfaces but where the user still must have some working knowledge of programming (e.g., Easy Java Simulations).

The first successful computer modeling system in physics education was the DMS, the Dynamical Modeling System (Ogborn, 1985), used in the Nuffield Advanced Physics course in the early 1980s. The approach used in DMS simplifies modeling by reducing the programming load: the user must write only the equations, usually iterative equations and the system has graphical and table windows to show computed values. This approach

¹ After this paper has been written, Jon Ogborn pointed out to me that there is an early reference: Bork, A. M. (1967). Fortran for physics. Reading, Mass.,: Addison-Wesley Pub. Co.



Figure 3: A model of a damping oscillator done with a "system dynamics" tool (Stella) and with Modellus.

influenced many other modeling tools: that is the case of Modellus. But Modellus' goal is more than just mathematical modeling: it can also be used to create simulations with interactive objects with the mathematical properties expressed in the model and to analyze experimental data in the form of images.

There is also another approach, in my view wrongly known as "system dynamics" (wrongly because there are many approaches to system dynamics, not only the flux and flow metaphor, characteristic of the "system dynamics" approach). In "system dynamics" tools (see Figure 3, top), variables that are integrated (accumulating change), are represented by "boxes" / "stocks", rates of change by "taps" / "flows" and parameters by "converters" / "circles".

Figure 3 shows the same model in Stella (probably the most well known tool for "system dynamics") and Modellus. While in Modellus initial conditions, parameters, and algebraic and differential equations are explicitly visible in mathematical notation, in "system dynamics" software equations and values are apparently hidden from the user (but they must be given by the user, clicking on icons and inserting data and equations on "dialog boxes"). In the case of Stella, the user must also select for each "flow" / rate of change the property "bi-flow" (this allows negative values for the rate of change) and the property "allow negative values" for each "stock".

Does it make sense to use a flux, flow, and stock metaphor for modeling in physics education? I strongly argue that this approach can induce physics educators to become confused about the language and nature of mathematical modeling (as described in Table 1). This metaphor is particularly confusing for describing variables with rates of change that depend on another rate of change (second order integration, such as computing acceleration). And what does a "negative flow" of position mean? "System dynamics" models have also strong ambiguities when describing vector quantities, particularly as compared with Modellus models where vectors can be manipulated in the Animation Window.

Other computer tools for modeling

It is easy to find on the Internet many mathematical modeling tools. A possible classification of these tools is shown on Table 2. The table only considers tools that allow the user to create and manipulate any type of models: it does not consider specific software for particular mathematical models.

Type of tool	Example(s)		
Programming language	C, NetLogo, StarLogo		
System Dynamics	Stella, PowerSim		
Spreadsheet	Excel		
General purpose tool with	Mathematica, Mapple,		
numerical and symbolic	MatLab, Octave		
computation			
Equation based	Modellus, Easy Java		
	Simulations		
Cellular automata	WorldMaker		
Semi-quantitative	VnR, Model-it		

Table 2: Classification of mathematical modeling tools for physics education

The subject of this paper is not the last two types of tool, cellular automata software and semi-quantitative modeling tools. I will just make a short comment on each type. Cellular automata software seems to have
a place in moderns physics courses, as has been shown in the second volume of the Advancing Physics curriculum (Ogborn & Whitehouse, 2001). In this course, phenomena such as percolation are for the first time treated with formal models in introductory physics. Semi-quantitative tools (also known as "qualitative modeling tools") have been around for about twenty years but it is difficult to identify any impact in the curriculum. "Qualitative tools" have an important didactical problem: they use formal representations for mathematical quantities and relations (boxes, arrows, line graphs without scales, etc.) that need advance knowledge to make sense of them – and a "metrics" problem: to express any quantity, one needs to define measurement units, a concept that is not present in "qualitative tools".

Why is modeling not embedded in most physics curricula? Too many varieties of modeling?

Looking carefully at general physics courses it is difficult to find modeling approaches, using all the concepts listed in Table 1. The typical course still follows the approach of Physics, from Halliday & Resnick (2005), first published in 1960. There are exceptions, in many countries, but it is uncommon for example to find any introduction to differential equations and to numerical methods for solving equations, particularly motion equations (there is a well known exception, the classic Feynman's Lectures in Physics (Feynman, Leighton, & Sands, 1963), where numerical solution of the equations of motion is explained in detail and is compared with analytical solutions.

The spread of the use of computers now makes it possible to create curricula that have mathematical modeling approaches: most if not all students have personal computers and it is now time to start taking profit of this. But there is a problem for curriculum developers: which tools for modeling should be used? The fact that there are many varieties of tools for mathematical modeling makes it a difficult choice. Software like Easy Java Simulations (Esquembre & Zamarro, 2001) are very powerful but require familiarity with some high level programming concepts that cannot be expected from high school or undergraduate students. For the same reason, it doesn't make sense to consider programming languages. And "system dynamics" software also doesn't make sense, for different reasons, as described above.

General purpose tools with numerical and symbolic capabilities can be a good choice, particularly for advanced students and, evidently, for symbolic computations. But they are generally not easy to use, even to build simple models. Figure 4 illustrates this issue with the same model presented in Mathematica and in Modellus. Mathematica syntax must be carefully checked and is frequently difficult to understand and memorize. The Figure doesn't show any simulation done with Mathematica (it can be done, but the syntax is really complex!). On the contrary, Modellus models are very close to or almost the same as "normal" written

equations, and numerical integration can easily be done as can be seen in the Figure. Modellus simulations are created in the Animation Window, using objects like vectors, graphs and particles, which have properties described in the Model Window.

In conclusion, it can be said that besides spreadsheets, a natural tool for mathematical modeling in physics education, as the example in Figure 1 illustrates, there are places in the general physics curriculum for equation based modeling tools such as Modellus and general purpose tools, particularly for symbolic computations and for more advanced students.



Figure 4: Modeling the bungee jumper with Mathematica and with Modellus.

The structure and content of a general physics course with embedded modeling

Physics I (main themes are: particle and rigid body motion; linear, angular momentum and energy conservation; oscillations; gravitation) is

a difficult subject with a high level of failure in the college where I teach. There are multiple reasons for this, ranging from underprepared students to the inefficiency of lecture classes. A new course is being designed to overcome the massive failure of students in the current course,

substituting the format "lecture plus practical labs" with a "project and workshop" format based on a modeling approach. Some of the features of this new one semester course will be the following:

- the course is activity-based, with students working in groups of two with computers;
- the course will focus only on a few sets of problems and phenomena that are easy to observe and for which it is easy to get real data from real contexts;
- data logging and modeling software (Excel, Modellus and Mathematica) will be used in all classes;
- all documents, student work, tests, etc., will be managed using a computer learning management system (Moodle).

Table 3 shows the content of the course. For each of the five problems, each student will write a short paper with the main concepts, principles and ideas, as well as create his own set of computer files with models and data.

	А	В	С	D	E	F	G	Н	I	J	К	L
1												
2		The Law o	f Universal Gra	vitation and	d Moon's or	bit, a num	erical solution	6 ::				
3											- 5	_
4		G=	6.67E-11	gravitation	al constant			$\sum F_{x}$	$a = \sum F_{i}$	x		
5		mT=	5.97E+24	Earth mass	, in kg		ä	× =	-x m			
6		mL=	7.36E+22	Moon mass	, in kg		dv		$V_{x, t+dt} = V_{x, t}$	$+a_x \times dt$		
7	1	roL=	3.84E+08	radius, Mod	on orbit (m))	d	$\frac{x}{x} = a_x$	$X_{t+dt} = X_{x,t}$	$+ V_{x,t} \times dt$		
8		TL=	2.73E+01	orbital peri	od, Moon (s	s)	u		Xn. dn = X n	+V. s. de× C	t (better!!!)
9	1.00	vL=	1022.903591	Moon spee	d (m/s)		<u>u</u>	$\frac{x}{x} = V_x$	···+ut ···x, t	· · x, t+ut		,
10		dt=	3600	time incren	nent		0	<i>c</i>			·	
11												
12				Moon acce	lleration		Moon velocit	y.	Moon coord	linates	distance to	Earth
13	t in days	t in sec	g on the Moo	а	ax	ay	VX	vy	х	У	r	
14	0	0	1.98754E+20	0.0027	-0.0027	0	(0 1022.904	384000000	0	3.84E+08	
15	0.041667	3600	1.98772E+20	0.002701	-0.0027	-2.6E-05	-9.7216552	1022.904	383965002	3682453	3.84E+08	
16	0.083333	7200	1.98789E+20	0.00270	0.0027	F 2F 0F	10 4407411	1022.01	202005005	7364570	3.84E+08	
17	0.125	10800	1.98807E+20	0.00270			1000000000	1			3.84E+08	
18	0.166667	14400	1.98824E+20	0.00270				-			3.84E+08	
19	0.208333	18000	1.9884E+20	0.00270				-			3.84E+08	
20	0.25	21600	1.98857E+20	0.00270				3			3.84E+08	
21	0.291667	25200	1.98873E+20	0.00270				-			3.84E+08	
22	0.333333	28800	1.98888E+20	0.00270			50000000	-			3.84E+08	
23	0.375	32400	1.98903E+20	0.00270			-				3.84E+08	
24	0.416667	36000	1.98918E+20	0.00270			/				3.84E+08	
25	0.458333	39600	1.98933E+20	0.00270			/	1			3.84E+08	
26	0.5	43200	1.98947E+20	0.00270			1	1	1		3.84E+08	
27	0.541667	46800	1.98961E+20	0.00270				4			3.84E+08	
28	0.583333	50400	1.98975E+20	0.00270	-1000000	0000 - 500	000000	¢ 5/	00000000 1	0000000000	3.84E+08	
29	0.625	54000	1.98988E+20	0.00270				1 /			3.84E+08	
30	0.666667	57600	1.99001E+20	0.00270				1			3.84E+08	
31	0.708333	61200	1.99013E+20	0.00270			500000000	1			3.84E+08	
32	0.75	64800	1.99026E+20	0.00270			-500000000	1			3.84E+08	
33	0.791667	68400	1.99037E+20	0.00270				-			3.84E+08	
34	0.833333	72000	1.99049E+20	0.00270]			3.84E+08	
35	0.875	75600	1.9906E+20	0.00270]			3.84E+08	
36	0.916667	79200	1.99071E+20	0.00270			- 1000000000]			3.84E+08	
37	0.958333	82800	1.99081E+20	0.00270			1000000000				3.84E+08	
38	1	86400	1.99091E+20	0.00270							3.84E+08	
39	1.041667	90000	1.99101E+20	0.002705	-0.00263	-0.00064	-241.076378	995.0106	372670652	91189898	3.84E+08	
40	1.083333	93600	1.9911E+20	0.002705	-0.00262	-0.00067	-250.535929	992.6959	371768722	94763603	3.84E+08	
41	1.125	97200	1.99119E+20	0.002705	-0.00262	-0.00069	-259.973249	990.2903	370832819	98328648	3.84E+08	

Figure 5: A typical Excel model expected as competence of students at the end of the Physics I course described on Table 3: the motion of the Moon using the Euler-Cromer method. With this model students can, for example; "see" that the Moon falls 1 mm for each 1000 m that goes "straight on"; test the value of escape velocity; analyze the conditions for different types of trajectories; etc.

Problem	Some concepts and principles	Examples of computer models
Crossing a river and sailing in open sea	Vector and scalar quantities. Velocity and position. Vector components. Vector addition and subtraction. Computing new position from velocity and time interval. Position as a result from integration of velocity.	Figures 1 and 2 (velocity and change in position, in Excel and Modellus) show typical examples of computer models that students will build and analyze.
From free fall to parachute fall, bungee- jumping and oscillations	Particles and rigid bodies. Force laws. Numerical and analytical solutions of the equations of motion (including Euler-Cromer method for solving second order integration). Terminal velocity and damping. Kinetic and potential energy. Energy conservation and dissipation. Natural frequency of oscillators. Forced oscillations and resonance.	Figure 4 (Modellus bungee jumper model) is a typical example of a model that students will make. Other models include: Solving the equations of motion numerically in Excel (including parachute fall before and after opening the parachute, bungee-jumping and oscillations). Solving the equations of motion analytically with Mathematica (including parachute fall and oscillations, with and without damping).
Rigid body motion: the case of the yo-yo	Translation and rotation. Center of mass, torque and angular momentum. Rotational quantities as vector quantities.	Modellus models of bars rotating with constant angular momentum but variable length.
Billiard collisions and the meaning of conservation laws	Conservation of energy, linear momentum, and angular momentum. Conservation laws and symmetries.	Mathematica models for solving systems of equations expressing conservation laws
The Moon, the apple and universal gravitation	Universal gravitation and relation between free fall, projectiles and orbits. Energy and escape velocity.	Figure 5 shows a typical example of an Excel model of an orbit that students are expected to build (in Excel but also and in Modellus).

Table 3: Content of a Physics I course, problem solving and project/workshop format, with embedded computer modeling activities

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Measuring and Improving Student Mathematical Skills for Modeling

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Abstract

The primary focus of this paper is on necessary pre- or co-requisite student knowledge needed to understand modeling and use it to solve problems. We discuss how student understanding of two such areas of knowledge, recognizing equations as functional relationships and vectors, can be evaluated using the *Mathematical Modeling Conceptual Evaluation (MMCE)*. Methods to improve student learning in these areas are described (analytic modeling and *Visualizer*®) and preliminary student-learning research results for traditional and reform courses are presented.

Introduction

We have worked for years to produce activity-based curricular materials, methods, and technological tools (e.g. real-time data logging or "MBL" tools) that help students to understand physics concepts by interacting with the physical world and we have worked to understand student thinking. In fact, we have had some success in helping students understand concepts and in understanding their thinking (Thornton, 1999).

We are now involved in an even more difficult task which is to help students to understand physics in terms of modeling (mathematical and other). We would like to set a more general context for the specific topic discussed in this paper. We planned a number of tasks for our modeling work.

- Present physics as the exploration of the physical world & the construction, validation, and application of conceptual models
- Create tool-based software
- Develop tools and techniques to aid students to learn and to relate different depictions and representations
- Create activities that begin with and return often to the physical world
- Evaluate students to determine necessary pre- or co-requisite knowledge.

We have also imposed a number of pedagogical requirements for our modeling software. It must enhance activity-based collaborative learning, allow authentic data collection and modeling tasks, support guideddiscovery curricular materials, address learning difficulties identified through education research, and work in actual classrooms and laboratories with a wide range of students.

Figure 1. MMCE Linear Function. Part 1: Coefficient is changed. Pick appropriate graph. Part II: Identify graphs where the chosen coefficient is positive, negative, or zero.



The primary focus of this paper is on necessary pre- or co-requisite student knowledge needed to understand modeling and use it to solve problems. Some of these "necessary" understandings are:

- An understanding of the behavior of the physical world in the topic area (preferably through experimentation)
- Conceptual understanding of the topic area
- Mathematical skills and knowledge
 - Recognize equations as functional relationships
 - Rates of change
- Understanding depictions and representations (overlaps with mathematical)

- pictorial
- graphical
- vector
- Specific modeling techniques and tool use
- Solving modeling "problems" and general problem solving are necessary for students to understand physics even without a modeling orientation. In some instances it is possible for students to gain the mathematical understanding while doing modeling tasks. An example is given below where students learn to recognize equations as functional relationships while doing analytic modeling in Workshop Physics.

How might we measure student mathematical understandings and improve them?

I am not actually able to tell you precisely how and what students understand. However, I can present a reasonable model that displays some important features about particular topics. In some sense we are modeling student knowledge about modeling. I have picked two examples to discuss in this paper. From the category "Mathematical skills and knowledge" we will look at how well students recognize equations as functional relationships and from the category "Depictions and Representations" we will look at student knowledge of vectors. In both cases we will also examine ways to improve student knowledge.

Equations as functional relationships

The author and Priscilla Laws developed the *Mathematical Modeling Conceptual Evaluation I (MMCE-I)* to measure student understanding of equations as functional relationships. Other parts measure understanding of rates and understanding of vectors which is addressed below.

We will look at two parts of the *MMCE-I* that evaluate functional understanding: the first addresses knowledge of linear equations and the second quadratic functions.

Some questions on the *MMCE* designed to evaluate knowledge of linear relationships are shown in Figures 1 and 2. In Figure 1 when a coefficient of a standard graph is changed in some way, students must pick an appropriate new graph. In a second set of questions, students must identify graphs where the chosen coefficient is positive, negative, or zero. Figure 2 requires students to describe how coefficient(s) is (are) changed to make one graph into another.

Figure 2. MMCE Linear Function. Identify how coefficient(s) is (are) changed to make one graph into another. (There are three more questions of this style.)



Figure 3. MMCE Quadratic Function. A physical change is made. Identify how the coefficients will change.

$x = d t^2 + e t + $	$\cdot f$	×	Sta	andard Situation	n	
Change(s) made to the standard situation.	I. Which graph describes the new motion?	II. Which coefficient(s) increase in magnitude?	III. Which coefficient(s) decrease in magnitude?	IV. Which coefficient(s) remain the same?	V. Which coefficients become or remain zero?	
 The slope of the ramp is increased so that it is steeper. 						
 The cart is given a harder initial push up the steeper ramp. 						
 The ramp is returned to the original slope and the cart is started further up the ramp at t=0. 						
 The clock is started after the cart has already begun moving up the ramp. 						
5. The ramp is placed in a horizontal (level) position.						

Those designed to evaluate knowledge of quadratic functions are shown in Figures 3-5. Note in Figure 3 that quadratic function is contextualized while the linear function was not contextualized. We originally tried to use a de-contextualized context for quadratic equations but even physics professors had considerable trouble. The contextualized context works well for evaluation of equations as functions. Figure 3 shows questions where physical change is made to the cart and ramp system. Students must identify how the coefficients will change. Figure 4 shows questions where the coefficients of a standard parabola are changed and students must identify an appropriate graph. ure 5 shows questions that ask students to identify coefficients related to a particular physical situation. Students must identify an appropriate graph. Figure 5 shows questions that ask students to identify coefficients related to a particular physical situation students ask students to identify coefficients related to a particular physical situation.





Figure 5. MMCE Quadratic Function. How are coefficients related to the physical situation?



Figure 6. Result of 26 US physics professors who participated in a modeling workshop answering some of the questions in Figure 4.

The physical context is changed. How do coefficients change? Which graph is now correct?						
$x = d t^2 + e t + f$ The task is still not easy. Results from 26 physics professors.						
Change(s) made to the standard situation.	I. Which graph describes the new motion?	II. Which coefficient(s) increase in magnitude?	III. Which coefficient(s) decrease in magnitude?	IV. Which coefficient(s) remain the same?	V. Which coefficients become or remain zero?	
 The slope of the ramp is increased so that it is steeper. 	46%					
 The cart is given a harder initial push up the steeper ramp. 	33%					
 The ramp is returned to the original slope and the cart is started further up the ramp at t=0. 	88%					
 The clock is started after the cart has already begun moving up the ramp. 	100%					
5. The ramp is placed in a horizontal (level) position.	79%]

How well can professors and students answer these questions?

Figure 6 shows the percentage of 26 physics professors in the US who identified the appropriate graph. (Graph choices shown in Figure 4.) The results are surprising and they certainly indicate this is not a trivial task. How do students do? First let us look at results for non-majors after traditional instruction in a university introductory non-calculus course at a selective university. Figure 7 shows that students after traditional instruction can get about 60% of the linear questions right. The quadratic questions are clearly not known well. While the results did not please us, we did



Figure 7. Percentage of correct answers for questions on the MMCE by algebrabased introductory physics students at a selective US college. Figure 8. Percentage of correct answers for questions on the MMCE by calculusbased introductory physics students at a US public university. Pre-instruction is compared to results after a curriculum with modeling activities.



have some hope that we could correct the problem with additional instruction. This idea was based on the fact that student scores on conceptual questions in classes such as these after traditional instruction were only in the range of 25% and after introducing *Interactive Lecture Demonstrations* (Sokoloff &Thornton, 2004, Thornton &Sokoloff, 2006) were over 90%. Since more students were able to answer the mathematical questions after traditional instruction we thought it my by easier for the rest to learn it. The problem turned out to be more difficult than we imagined.

Figure 8 shows the percentage of correct answers for questions on the *MMCE* by calculus-based introductory physics students at a US public university. Pre-instruction is compared to





Figure 10. Percentage of correct answers for quadratic questions on the MMCE by calculus-based introductory physics students at US institutions.



results after a curriculum with modeling activities. The results show hardly any improvement in mathematical understanding.

A mild confession and a success story

We have learned to measure reliably student conceptual understandings in both traditional and reform courses. The results of such measures are sometimes not well received by instructors teaching traditional courses.

Units	Topics	In-Class	нพ	Functions
1-7	Kinematics & Dynamics	12	8	Linear, Quadratic
8-11	Momentum & Energy	7	7	Linear, Quadratic, Inverse
12-15	SHM, Rotations & Chaos	7	3	Linear, Quadratic, Sinusoidal
16-18	Thermodynamics	7	3	Linear, Inverse, Exponential
19-27	Electricity & Magnetism	8	1	All of Above & Inverse Square
	Total	41	22	
Units	Topics	In-Class	HW	Functions
1-14	Dson Semester 1	22	14	Primarily Linear & Quadratic
15-27	Dson Semester 2	19	8	Also sinusoidal, inverse, Exp

Figure 11. Modeling use in Workshop Physics.

Note: HW use has been approximated for AY $\bar{\mathbf{O}}9-\bar{\mathbf{O}}0$ to present. Modeling Homework was *very* minimal in $\bar{\mathbf{O}}5-\bar{\mathbf{O}}6$





After hearing "my students may not know concepts but they understand mathematics" from instructors of traditional physics courses (usually after giving the FMCE or FCI) we wanted to measure students mathematical knowledge in both traditional and reform instruction and see if students actually understood mathematical concepts. We developed the *MMCE* to serve this purpose. A very successful reform physics program, Workshop Physics (Laws, 2004,1991), places considerable emphasis on conceptual knowledge but also emphasizes mathematical understanding and analytic modeling skills. Figures 10 and 11 compare the results of students in the calculusbased Workshop Physics program with those in students a traditional physics program in a good comprehensive university. The result shows that students in a calculus-based physics course in a comprehensive university only scored 54% (on linear questions) and 39% (on quadratic questions). So it seems that many students in traditional programs not only

do not learn concepts well but also do not understand fundamental mathematical concepts. Students in the activity-based Workshop Physics (who learn concepts and mathematics) scored 77%(on linear questions) and 59%(on quadratic questions) the first time they were given the

MMCE. After seeing the results, some additional analytic modeling homework was added and the scores have increased to 94%(linear) and 72%(quadratic). These results do not come without effort.

Analytic modeling in Workshop Physics

What is analytic modeling? Students use computer data collection, graphing, and analysis software (e.g. LoggerPro, Coach) to make a visual comparison of data with an analytic function suggested by a mathematical model. They manipulate the parameters manually which enhances their understanding of the meaning of each of the model's parameters and strengthens the students' ability to relate analytic and graphical representations of functional relationships and physical phenomena. Figure 11 shows the number of instances of analytic modeling done in the activity-based classes and those assigned as homework questions. Some particular instances where analytic modeling is used for analysis include ball toss, a mass on a spring, and coulomb repulsion. In all these cases students collect actual data and analyze it. It is necessary for learning for students to do more than one modeling task with each equation.

Student Understanding of Vectors

The *Mathematical Modeling Conceptual Evaluation II (MMCE II)* was designed to measure students' conceptual understanding of vectors just as the *MMCE I* measured students' understanding of mathematical functions in the context of modeling. The *MMCE II* measure student knowledge about:

- Vector addition and subtraction
- Components
- Vector Change
- Axis Rotation
- Scalar and vector products

Figures 12 and 13 show the first two categories. All vector questions are context independent. It might not be a surprise that traditional physics courses are largely ineffective in improving student understanding of vectors. Student understanding of vectors as measured using part of the *MMCE-II* showed less than a six percent improvement before and after standard instruction in the Tufts introductory physics class. Less than half of the students understood vector concepts. However, student understanding of vectors before instruction gave us false hope, just as happened with the understanding of functions. In this same class students' conceptual knowledge of Newton's Laws started at 10-15% and traditional instruction had little effect, yet our activity-based curricula resulted in 90% post-test scores (see previous section). Therefore, we thought starting near 40% for vector knowledge would make further gains easier than our previous conceptual gains. We were wrong again.



Figure 13. MMCE II Vector Evaluation-Vector Components

We used a vector *Interactive Lecture Demonstration* in class (about 30 minutes) and we assigned a web-delivered vector dynamic tutorial (4) as homework. Both use the *Visualizer*® The *Visualizer*® can display physical data or the output of models in 3-D vector form, including time evolution and trajectories. It understands vector operations and can display 3D vectors graphically and algebraically. Users can change

Figure 14. Web-delivered interactive tutorial with the Visualizer $\mbox{$\mathbb{R}$}$ showing in the window

Vector Subtraction



Vectors can also be subtracted and multiplied. Subtracting **b** from **a** is the same as adding -**b** to **a**. (-**b** is a vector in the opposite direction from **b** but equal in magnitude (length)). In this example **c** is defined as $\mathbf{a} - \mathbf{b}$. Both **b** and -**b** are shown.

Click the animate button to see the ghost vectors form the sum $\mathbf{a} + (-\mathbf{b})$

Change a and b and see what happens to the difference.

The vector **-b** has been created by multiplying the vector **b** by **-1**. This is an example of multiplication by a number to create a new vector. Show that \mathbf{a} +(**-b**) is the same as \mathbf{a} - \mathbf{b} by translating the vector **-b** and \mathbf{a} to show that their sum is also \mathbf{c} .

How is the vector **b**-**a** related to the vector **a**-**b** in magnitude and direction? After predicting, check your answer by subtracting **a** from **b** in the algebra window and comparing the result with **c** (which is **a**-**b**). Next: Vector Changes

Next: Vector Changes Previous: Vector Sum Menu:

vectors dynamically, observer viewpoint, and coordinate systems. Figure 14 shows and an example of the web-delivered

Interactive Vector Tutorial with the Visualizer® showing in the window. Students can manipulate the vectors in the window. As a result of using the vector *Interactive Lecture Demo* and the web- vectors in the window. As a result of using the vector Interactive Lecture Demo and the webdelivered Interactive Vector Tutorial as homework, we achieved the results shown in Figure15 at Tufts University where 60% of students who did not know the vector concepts learned them. The results are certainly acceptable, but still not what we would wish. Modifications have improved results and results are getting better as shown by the other normalized gains in Figure 15 for very different groups of students. Notice again that reform curricula such as RealTime Physics (Sokoloff, Thornton & Laws, 2004) and Workshop Physics result in more learning of vector concepts than traditional instruction where the improvement is extremely small. The most successful combination for teaching vector understanding was at Joliet Community College where RealTime Physics mechanics and the Interactive Vector Tutorial were used. Students answered over 90% of the questions correctly. It is also clear that computer visualizations can work reasonably well in the curricular contexts we have been discussing.

Figure 15. Normalized gains using part of the MMCE-II to evaluate knowledge about vectors. Students experienced various instruction as noted. Students taking RealTime Physics mechanics and Workshop Physics make substantial gains in vector knowledge unlike standard instruction.



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Motivating teachers and pupils to engage with modeling.

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Abstract

It has been found that science teachers in secondary schools have embraced the use of simulation software more enthusiastically than modeling software. Some simulations are visual aids, chosen for their ability to help pupils visualize complex or abstract phenomena. Others feature virtual experiments which allow pupils to perform pseudolaboratory activities and obtain quasi-experimental data. In both cases it is common for the software to facilitate activities which support the development of valuable skills for scientific investigation. It is argued that modeling software has even greater potential for developing these skills towards a deeper level of scientific understanding. However, many modeling software systems possess a conceptual and presentational format which appears to be less accessible than graphically-rich simulations. The paper describes a new type of software of hybrid design which attempts to build bridges between apparently successful simulations and potentially more demanding modeling activities. The development involved careful consideration of the language used for expressing scientific concepts and relationships, contextual factors which influence motivation and the design of tasks to promote effective use of the software tools.

The adoption of ICT in science lessons

At the present time in the UK young teachers entering the profession have sometimes been described as 'digital natives', having been surrounded from birth by the products of information and communication technology. Their environment of computers, Internet, mobile phones and wireless technology has equipped them with technical skills and confidence which many 'digital migrants' of the previous generation of teachers have struggled to achieve. The effect of this has helped transform the adoption in schools of ICT tools for teaching and learning. However, some tools have succeeded more than others. In a survey of science teachers in the UK, one of the most popular types of application was simulation software (Rogers & Finlayson, 2003). The possibilities for simulating physical phenomena with the use of animated graphics were widely appreciated as valuable teaching tools. In a wider survey across several European countries prepared by the IT for US project (www.itforus.oeiizk.waw.pl), of the different types of software to be found in secondary schools, simulation software comes out with a consistently higher score than do other types.

In particular, there is a contrasting response for modeling software, whose function is very closely associated with simulations, but appears to be less widely used.

Country Software type	Cyprus (%)	Netherla nds (%)	Poland (%)	Portugal (%)	UK (%)
11.1 Presenting and reporting software (word processor, electronic presentations, (web pages)	63	79	67	72	90
11.2 Tutorial software	7	32	52	17	29
11.3 Information storage systems (databases, encyclopedias, multimedia CD's, web-sites, etc)	43	75	57	63	90
11.4 Simulation and visualization software	47	83	36	65	86
11.5 Calculating software (spreadsheets, statistical or mathematical programs)	10	62	32	56	52
11.6 Modeling software (Coach, Modellus, Insight, PowerSim, Stella, etc)	3	81	10	59	24
11.7 Measuring tools (data logging, video measurement)	50	84	6	35	76
11.8 Sound analysis software	0	50	11	19	20
11.9 Drill and practice programs (revision etc)	3	42	24	15	62
11.10 Software for monitoring student's progress	7	24	12	13	29

Table 1. Types of software used in science lessons (IT for US Project, 2006)

Simulations and Modeling software compared

For the purpose of developing the present discussion, it is necessary to distinguish between simulation software and modeling software. Both

types of software share similar pedagogical aims and employ similar mathematical techniques. Both attempt to help the learner explore and understand physical phenomena in a virtual environment. Both may be used to facilitate investigative inquiry, the exploration of relationships between variables, the testing of hypotheses and so on (page 84, Newton and Rogers, 2001). However, on inspection, an obvious distinction is in the design of the user interface; modeling software is usually of a generic, symbolic design (e.g. as in Stella, Excel, Modellus programs) whereas simulations usually offer a graphical interface customized to the needs of the topic under consideration. A more significant difference is that, although every simulation employs a mathematical model as an 'engine' to perform calculations, the model is usually not explicit or accessible to the user. In contrast, modeling software allows all the mathematical definitions and assumptions in the model to be scrutinized and, if desired, edited and modified; there is greater freedom for controlling and choosing the mathematical expression of relationships between variables. Thus, activities with modeling software can probe more deeply into the assumptions inherent in the design of the model, potentially pose more questions about possible alternatives and

ultimately facilitate a deeper scientific understanding. Table 2 suggests a comparison of the distinctive differences between modeling software and simulations.

It should be remarked that a considerable number of simulations are mainly offered as graphical animation aids for visualizing phenomena. Many so-called 'applets' fall into this 'visual aid' class of simulation. The other class of simulation may be termed as 'virtual experiments' in which data is generated for analysis and relationships may be explored.

To explain the apparent preference for simulations over modeling, it is possible that the simplified subset of tools and implicit guidance inherent in simulations makes them more accessible than modeling programs, which, although they allow greater degrees of freedom, their successful use demands more insight and skill on the part of the user. Another explanation might be found in the teaching styles adopted by teachers. In a recent UK teacher training program in ICT methods in science teaching, it was found that the most common mode of use of simulations was as a teacher demonstration. (Table 3). Teacher exposition is a dominant pedagogy for many teachers, and it appears that teachers' skills in explanation and demonstration are readily adapted to the use of simulations. It may be argued that teachers readily identify simulations as tools with which they can engage in discourse with a whole class of pupils. The thesis to be developed in this paper is that suitably designed software can exploit teachers' positive disposition towards simulations to lead them towards more demanding modeling techniques.

Simulations	Models
The designer has a major role in defining the user interface and scope of possible investigations.	The user has freedom to examine, adjust and modify the model.
Appropriate tools for presentation and analysis are pre-selected (displays,	The user may choose from a broad range of tools for analysis and presentation.
graphs, axes, cursors, controls and calculating aids)	A model makes the physical principles more explicit.
	A model can show how a solution to a complex problem may be synthesized from simple elements based on first principles.

Table 2. Differences between simulations and models

Type of activity	Individual (%)	Group (%)	Demonstration (%)
Internet	46	44	10
Data-logging	2	33	65
Simulation	19	13	68
Spreadsheet	39	39	22
Using models	30	38	32

Table 3. Comparison of teaching formats for different ICT activities. (Rogers and Finlayson, 2004)

Pedagogical objectives of modeling activities

Gilbert and Boulter (2000, page 13) describe three main contributions of modeling to science education. First, models have a central role in the development of the scientific understanding of any phenomenon. Second, the testing of models is an important process of science in action. Third, scientific models are major creative outcomes of science. Translating these into specific objectives for modeling activities, the most commonly stated objectives in practice are:

- To prompt thinking and exploration of scientific ideas.
- To assist the interpretation and understanding of real data (through a process of comparing data from a model with data from an experiment)

- To test the accuracy of a model and to evaluate its implicit assumptions.
- To make possible the virtual exploration of otherwise expensive, remote or dangerous experiments.
- To simplify the solution of complex problems in terms of simple elements.
- To facilitate the extension or reinforcement of previous learning.
- To provide opportunities for revision exercises.
- To rehearse experimental procedures employed in laboratory work.
- To build confidence in analyzing data. (Models can generate 'noisefree' data which allow clear conclusions to be drawn about relationships.)

As previously indicated, activities with modeling software share many common objectives to those of activities with simulations; the main distinction arises from the level of access and the depth of investigation. Of course all models and simulations are built upon assumptions about the variables involved and the scientific principles thought to govern them. The very process of challenging such assumptions is an integral aspect of science in action, so modeling activities which allow those assumptions to be challenged and tested provide an extremely valuable means of developing an understanding of science (Webb, 1993). Lawrence has argued that modeling tools fulfill the need of individual learners to find ways of expressing their own thinking about scientific problems (Lawrence, 2005)

The discussion will be developed by considering two case studies to illustrate a gradient of activities, starting with simulations and progressing towards tasks with models. In each case, a simulation provides a welcoming context which relates to a pupil's previous experience and attempts to stimulate their interest by posing questions for investigation. These require them to experiment with the variables involved and evaluate the results through applying their previous knowledge. This can involve graphical analysis of data generated by the simulation. Progression to modeling tasks usually begins with examining the model to review all the variables and the relationships between them. Crucially, new tasks with the model involve modifying the model to test alternative relationships. If desired, completely new models may be built. The modeling program used is Simulation Insight (Logotron, 2005) which contains in one window an authoring system for creating simulations and in another window a modeling system employing graphical objects to represent variables. The simulation window contains animated graphics whose movement and changes are driven by variables defined in the modeling window.

Case Study 1: Simulations of house insulation

The context for these simulations is very familiar to people who endure winters in central and northern Europe. House designers incorporate various ways of improving the thermal insulation of the building; cavity walls, double glazing and loft insulation. The first simulation allows the insulating properties of a cavity wall to be investigated. The user may control the outside temperature, the inside house temperature, the cavity thickness and the insertion of insulating wool.

As each of these variables are adjusted in turn, the effect on the rate of heat transfer may be observed and students can gain a qualitative perception of the relationship between the variables. Through more systematic control of the variables, data may also be recorded, graphs analyzed and a quantitative description of a relationship achieved.

The next step of the activity is to examine the model (Figure 2a). This is viewable in an alternative window. The model representation of connected blocks is designed to indicate the relationship between variables; each block represents one variable or constant. The geometrical layout may be freely organized to maximize the lucidity of the model. The arrows show how values are used in the calculation of secondary variables. In this case, the rate of heat flow H is calculated from three other variables, *Ti*, *T*o and *th*. *K* is a constant. Whilst the model is running, values are displayed in each block and input variables may be adjusted with slider and spinner controls (Figure 2b). The model may be investigated in a very similar manner to the way in which the simulation window was controlled and can be seen to generate similar results. However, the analytical appearance of the model, although less stimulating visually, gives a clear focus on the numerical changes occurring as input variables are adjusted, but more importantly, it makes the mathematical basis of the calculations quite explicit. In this case, the model assumes that the rate of heat transfer varies in proportion to the temperature difference across the wall section and inversely with the thickness of the cavity. The language of mathematical formulae allows this relationship to be specified precisely, and the program contains a formula builder to facilitate this. However the program also offers an alternative exploratory method of defining relationships which is textually based and less dependent on algebraic skills.



For Help, press F1. To tidy windows, press Ctrl+T.

Figure 1. Simulation of the insulating properties of a cavity wall.





Figure 2a. Thermal insulation model



The introductory tasks investigating the effect of each variable on the heat transfer had previously demonstrated the success of the pre-defined model in making credible calculations and predictions which seem to match experience of the phenomenon in real life. A design challenge to consider for less mathematically able pupils is how a successful alternative model might be built using only descriptive phrases to define relationships between the variables. The program allows this to be done using a text-based dialogue in place of the formula builder (Figure 3).

n Ti To H C th a hfo hfi K	Item inside temperature outside temperature heat loss cavity insulation cavity thickness air in cavity heat flow out heat flow in		Names Symbols	and increases as and increases as and increases in the same ratio as and decreases in the same ratio as and varies in proportion to and varies inversely proportional to	< >
) Links (< Pro	Description	Formula	Clear	Delete Cancel OK	

Figure 3. Dialogue for defining a relationship between variables

Having cleared the previous formula, pupils can point and click on appropriate phrases and variable names to build a description in words which expresses their idea of how the variables might affect each other. For example, each of these alternatives might be tried:

heat flow increases as inside temperature increases heat flow increases as outside temperature decreases heat flow decreases as cavity thickness increases

For each description, the model may set to run and the resulting behavior compared. In this example, each description successfully produces the correct trend which serves to confirm pupils' thinking about a relationship. This textual method works well for simple relationships, but unfortunately struggles to adequately describe complex multi-variable relationships, so is unable to offer a model embracing all the variables. To answer this problem, one must return to the original pre-defined model to see how these relationships are combined and expressed in a single formula. Ultimately the formula definition method gives greater precision and clarity, but modeling activity with the descriptions can be used in a formative way to promote thinking about relationships. This fairly simple simulation and model is useful as a preparatory exercise to a second more sophisticated simulation which calculates the internal temperature of a house, taking into account the insulating properties of doors, windows and the loft under the roof. The user may adjust the external air temperature and the rate of heat production by the boiler and observe how a new equilibrium becomes established according to the various insulation options. This is a dynamic model in the sense that, by including a time variable, it handles rates of change and shows how long it takes for changes to occur.



Figure 4. Model for house insulation

Case Study 2: Simulations of accelerated motion

These simulations consider various forces acting on a body and calculate the velocity and displacement for the resulting motion. The context for the first is the problem of pushing a car whose engine will not start. A car is the mass to be accelerated and the external force is supplied by a choice of one, two or three men. When 'Push' is activated, the car moves and a simultaneous graph shows the acceleration, velocity and displacement (Figure 5).

It is immediately evident that the constant force produces a constant acceleration, whereas the velocity increases linearly. Altering the number of men pushing changes the acceleration and the gradient of the velocity graph. If the men stop pushing, acceleration drops to zero, velocity becomes constant and the displacement graph is linear. These explorations give pupils an opportunity to distinguish between uniform acceleration and uniform velocity, and the role of external forces in determining the motion. Quantitative comparisons may be made by analyzing the graphs; for example, measurements of gradient on the velocity graph can be related to the acceleration.

As previously, the next step is to view the model in the alternative window. This reveals the mathematical basis of the calculations (Figure 6).

The model defines incremental calculations for velocity and displacement rather than absolute values which, in this program, are automatically computed. Newton's Second Law is assumed for calculating acceleration. Being based on basic principles and definitions, this model will be recognized as a basic building block of models for many other examples of motion such as that for a parachute which follows here. There are many opportunities for elaborating this basic model, the most obvious of which is to introduce a variable which takes account of friction. Herein lies the potential of modeling activities; complete access to the model, adapting it to accommodate additional conditions, modifying it to express alternative assumptions.



Figure 5. Simulation of moving a car by pushing.

The second simulation described here illustrates this sort of elaboration. This example features the motion of a parachutist jumping from an aeroplane. The simulation window (Figure 7) sets the context and invites the user to experiment with controlling a limited number of variables: the mass of the parachutist, the diameter of the parachute, the time of the jump and the time for opening the parachute. Initial activities can establish how the variables affect the time taken to reach the ground and how they may be controlled to ensure a terminal velocity which is safe for landing. Turning to the model, the core variables of time, acceleration, velocity and height fallen are recognized, with the additions of weight and air resistance as the forces involved. The total of nine variables suggests a moderately complex problem, but the geometrical layout with directional links shows a simplified pattern of dependencies. The summary list of definitions indicates that individually their origins are very simple: height, velocity and weight express basic principles, acceleration comes from Newton's Second Law. Air resistance is assumed to increase with diameter and velocity. Since air resistance affects acceleration, which in turn affects velocity, a 'feedback' loop of dependencies exists between these three variables.



Figure 6. Model for motion of car

To optimize the learning value of the simulation and model, the activities need to be carefully planned with clear objectives. The following sequence of outline questions and tasks is a possible framework for achieving this:

The general need for establishing an agenda of activities with simulation and modeling tools will be considered next.



Figure 7. Simulation of a parachute drop.

Planning curricular activity

Modeling and simulation tools are most effective when there is personal engagement of the learner. All the exploration and thinking described in this paper demands not simply response but commitment of the learner.

The broader experience of teachers makes them familiar with this requirement generally in science education and most have developed strategies for stimulating and motivating pupils to achieve this in a whole range of science skills. For modeling to succeed in the classroom, the challenge is to provide a framework within which the software tools can flourish. In recent years the concept of 'scaffolding' pupils' thinking to support an essentially personal learning process has emerged in pedagogy. Scaffolding implies a careful balance between instruction and learner autonomy. It demands clear learning objectives, an understanding of pupils' needs, dialogue, questioning, discussion and so on. The teacher is the best judge of how to manage this in detail, but let us consider some principles for guiding the planning of modeling activities.



Figure 8. Model for parachute motion

The freedom offered to pupils when presented with modeling software in a content-free state can be extremely daunting. Designing and building a model from scratch probably poses the most sophisticated demands on pupils and is a skill to be aspired to rather than to be exercised as a first activity. Newton and Rogers (2001, pages 89-93) have described a hierarchy of task levels in the use of spreadsheet software, which may be readily adapted to modeling software thus:

Task Level 1: Exploring an existing model.

Pupils are presented with a previously prepared model and activities focus on studying patterns and relationships in the data generated by the model. Familiarization with a range of data analyzing tools is required. Activities should build confidence in obtaining useful data from the model and interpreting their significance.

Task Level 2: Modifying a model

The additional demand at this level is to understand more of how the model works and to edit some of its components or add new components.

The purpose of activities is to make the model behave differently to yield new or different data which more accurately reflect observations of the phenomenon in real life.

Task Level 3: Designing and building a model

This is the most sophisticated level of use, requiring pupils to identify variables and define relationships to replicate the behavior of a physical system. It demands all the skills exercised in the previous levels.

Simulation	Is the parachute big enough? – vary mass of parachutist How long does it take to reach the ground? – vary diameter of parachute When is it safe to open the parachute? – vary delay before opening
Graph	Describe changes of speed during the fall. Make suitable measurements. Compare the graph of velocity with the graph of air resistance.
Model	Examine the model and justify each relationship between variables. Alter the model to take account of thermal currents, changes of air density, wind, changes to the parachute shape etc.

Reflecting on the example tasks featured in the case studies, we can identify examples of task levels 1 and 2. If we also consider how activities with simulations fit into the hierarchy of tasks, it can be argued that simulations offer an even greater degree of scaffolding than Task Level 1. Not only is the model pre-defined, a simulation adds more support by limiting the scope of investigation, focusing attention on significant variables, selecting appropriate tools for display and analysis of the data produced. Taken with the graphical user interface, the simulation presents more user-friendly access than Task Level 1 such that it may be assigned Task Level 0. Thus simulations can provide an entry level for what ultimately can develop into an autonomous command of modeling tools at Task Level 3.

Conclusion

The case has been made for considering simulation software as a suitable entry point for engagement in the world of scientific modeling. The use of graphics and images in simulations reinforces context and enhances motivation. The guidance implicit in the pre-selection of variables for control and display and analysis options helps to minimize 'inauthentic' labor associated with the tasks (Wellington, 2005) and to maintain an emphasis on appropriate scientific thinking. Simulations vary in the amount of freedom ceded to pupils to make choices and fashion their own investigation (Osborne and Hennessy, 2003) but access to the model which drives the simulation is usually not allowed. It was to facilitate this transfer of thinking activity to the model itself that *Simulation Insight* was conceived. It has blurred the closed/open distinction between simulations and modeling. The program has also attempted to break new ground in providing a non-algebraic approach to developing thinking about relationships.

As is often the case with ICT applications, there is still much for the teacher to determine, in particular the schedule of activities involving the scripting, sequencing and grading of tasks.

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Photographs



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and everybody else ...

Impression of the plenary talks





The audience paying attention

Igal Galili



Max Bazovsky speaking passionately





Azita Seiedfadaei paying serious attention

Tjeerdo Wieberdink shows his stuff



Fun with liquid Nitrogen



Representative of the conference's target group



Paul Vlaanderen doing what he does best: experiments!



New GIREP president checks the boat


Impression of Amsterdam



Captain Fuller at the helm



The conference dinner



Ed van den Berg, Ewa Mioduszewska and Margeret Fuller



The auditorium of the University of Amsterdam



Hans Hulst, Piet Molenaar, Cees Mulder and Barbera van Ulzen, still looking sharp.

Modeling in the classroom: Linking physics to other disciplines and to real-life phenomena

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Abstract

New technologies provide us with powerful instruments for the modeling of natural phenomena, thus increasing the variety of situations which can be examined in an introductory physics course. At a general methodological level, the combined use of modeling and data acquisition systems allows teachers to highlight one of the most fundamental aspects of scientific activity, viz. the relationship between theory and experiment.

By focusing on the structure which underlies the functional relationships involved in a given situation, modeling also fosters the acquisition of transversal and interdisciplinary skills. The cognitive acts carried out by the students are particularly interesting because – and this is true above all for work-environments which offer a graphic interface – the students are required to consider not just singular, isolated notions, but rather a whole network of connections, a veritable conceptual map informed by quantitative aspects.

Preliminary considerations

In this paper I shall present some reflections that arise from my direct experience introducing high school students, and to a lesser extend preservice and in-service teachers, to modeling activities. As the title suggests, I shall limit myself not just to modeling in physics, but I also want to look at some aspects of modeling activity that can contribute to a better and deeper understanding of scientific activity as a creative but rigorous and coherent design for co-coordinated science teaching. Since it is possible that not all high school teachers have direct experience with modeling at this level, I have structured my presentation with the following questions in mind: Is it really possible to introduce high school students to modeling? What can they learn? What is the best way to proceed? And perhaps the most intriguing question: What is the advantage of such a didactical approach? My aim is not to convince you that my personal answers are correct, but rather to present some elements which may stimulate reflection on this matter.

Examples and materials used in the present paper arise from my practical work with high school students or with pre- and in-service teachers I have introduce to modeling activities². Obviously the skills of these two groups

² They are my own high school students from 16 to 18 years of age at the Liceo cantonale di Locarno, in total about 80 students during the last six years in groups of 15 to 20; the preservice and in-service teachers come from different post-secondary institutions such as the Alta Scuola Pedagogica of Locarno, the SSIS at the Università di Udine and at the Università di Padova.

and the methodology required to teach them are completely different, but it is interesting to compare the reactions, the questions and the solutions proposed by high school students on the one hand, and graduate students on the other.

A further remark concerns the high school students' knowledge of physics at the moment I introduce the modeling activities³: they are used to seeing natural processes on the basis of a model that stresses the role of the *extensive physical quantities*. that can be stored in a system and that can be transferred from one system to another by virtue of a "driving force", i.e. through the action of a *potential difference*. In particular the high school students are introduced to thinking in terms of the different extensive and intensive quantities that characterize the different fields: in hydraulics water volume, pressure difference and water current, in electricity, electric charge, electrical potential difference and electrical current, and in mechanics, momentum, velocity difference and force. Furthermore, students can already make use of the so-called *balance law*, i.e. the equation that in different contexts expresses the relationship between the instantaneous rate of change of the stored extensive quantity, the intensity of the flows through the boundaries of the system and, if at all admissible, the rate of production/destruction of the quantity in question.

As far as the mathematical background of the students is concerned, they have already been confronted with the basic ideas of a numerical algorithm and of an iterative procedure. In particular they can apply the Euler method to determine time evolution for a specific quantity by a given process: they have worked out laboriously on paper some iterative loops for suitable examples (that do not necessarily involve physical quantities, or where the results are easy to predict or already known from previous school activity) and they have also performed the same procedure in a more automatized manner, for example by using an electronic spreadsheet.

1. Introducing modeling to high school students

To introduce my students to a modeling tool, I have chosen software that allows them to work on a graphical surface. Physical quantities are introduced by one of the graphical symbols, four in all, while the relations between them must be implemented explicitly. If we consider a mechanical situation, for example a rigid body with two forces acting on it, we have the situation represented in Figure 1.

³ For a general presentation of this approach see F. Herrmann *The Karlsruhe Physics Course* [1]; for the English version of the course for high school students see www.physikdidaktik.uni-karlsruhe.de.

Figure 1 - Basic elements: a rectangle represents quantities stored in a system at a given moment while the arrows indicate that there is an exchange between the system and its surroundings.



We can read the diagram as follows: the rectangle represents the momentum of the rigid body; the initial value must be explicitly specified. The arrows represent the instantaneous momentum-flows between the system and the surroundings, while the small cloud symbolizes the surroundings. The whole scheme represents the *law of balance* for the momentum of the body: in fact, by drawing this combination of symbols we have implemented a first order differential equation.

As a first concrete example I often present the following situation: a rigid body (of given inertial mass M) which can move without friction on a horizontal surface and which is acted upon by a constant force (Figure 2).



Figure 2 - A constant force acting on a rigid body: visual and schematic representation.

Focusing on the law of balance of momentum, i.e. on the dynamical aspects of the situation, the students will be able to write down, or rather draw, the following Newtonian equation

(10)
$$\dot{p} = F_{ext}$$

For the students this means, expressed in words: "The force acting on a body determines how fast the momentum changes." They also understand that, for an interval of time where the force is constant, this can be expressed by

(11)
$$p(t) = p(t - \Delta t) + (F_{ext}) \cdot \Delta t$$

This is the form we commonly use to write our *laws of balance*. It is identical to the simplest numerical method used by the software to solve the differential equations iteratively. As already pointed out, before using the system dynamics tool, I have my students perform such a solution procedure on paper, then with the help of a spreadsheet.

The resulting equations that represent the model of our example can be visualized at will simply by activating the corresponding mathematical or formal level in the software:

(12)
$$p(t) = p(t - dt) + (Fext). dt$$

 $INIT p = 0 \{N.s\}$
 $INFLOWS:$
 $Fest = 2 \{N\}$

In order to create more complex models we require two further elements: auxiliary quantities and connectors (Figure 3).



The *auxiliary quantities* are represented by a circle and can be defined in different ways: for example as a constant quantity, simply indicating a numerical value, as here for the mass of the body; or alternatively as a function of other quantities, such as velocity in this example, given by the Newtonian constitutive relation "Velocity equals momentum divided by inertia".

The last symbol, the thin arrow, is the so-called *connector*, which indicates the interdependence between the different quantities. In our example the velocity of the body depends both on its momentum and on its inertia.

At this stage, the kinematical aspects can be introduced: the velocity of the body is interpreted as the instantaneous rate of change of position, so that the latter can be obtained by a stock-flow diagram (v. Fig 4) that, from the mathematical point of view, functions as an integrator.



Figure 4 - Kinematical aspect: the actual position is obtained adding the displacement to the initial position.

To recapitulate, starting from a given problem, we have *constructed*, step by step, a possible solution: we can now consider the model as a whole (Fig 5)



Figure 5 - The complete model: beside the graphical surface, the mathematical formal level is easy to access: there the graphically implemented general relationships are visible as algebraic algorithms, as well as the particular laws that define the model. The results can be visualized in the form of a graph or of a table.

Starting from this first example it is interesting to challenge the students with a second mechanical situation, namely, the *harmonic oscillator* (Figure 6).



We have here what at first may seem to be a completely different physical situation, but ... let us examine the previous model more closely, and ask ourselves which parts of the model are still useful, or alternatively which parts of the model must be changed.

Let us consider the model again in detail: the law of balance of momentum is still valid; the same holds for the constitutive law for velocity expressed as a ratio between momentum and inertia, the velocity of the body interpreted as the rate of change of position, and the same for the kinematical relation with the position. What, then, should be changed? In this way we see that in this new situation there is only one new feature: the constant force should be replaced by an elastic force to account for the action of the spring (which we will consider an ideal spring). We must introduce therefore into the model an elastic constant (k) to account for the elastic properties of the spring and implement Hooke's law in the model. Finally, the initial conditions must also be up-dated (Figure 7).

At this stage students generally expect that this new model will work very well, and they start the simulation. The result brings deep disappointment: instead of the expected oscillation it shows a huge increase of the relevant physical quantities. What is wrong with the model? With students this is an interesting point, because in this way they experience directly that a numerical tool is not a magic instrument and that there are still some limits to its applicability.



Figure 7 - The model for the harmonic oscillator: the only difference with the previous model is the introduction of the elastic constant k and the implementation of Hooke's law.

Students must first pay attention to the choice of the iteration interval; up to now the default settings of the tool have not been questioned: in the present situation, the default choice (0.25 seconds) is not appropriate because it is of the same magnitude as the expected oscillation period. So students can try with a much shorter iteration interval, for example 100 times smaller. The result is much better in that the solution becomes oscillatory, but it is still not satisfactory, on account of the continuous increase of the amplitude.



Figure 8 – Numerical aspects: students gain the feeling that numerical methods always have limits of applicability.

This second point is more difficult to discuss explicitly with students, because it is connected with the peculiarities of the integration method used. In fact, here, one comes up against the limits of Euler's method: by a more refined method (for example Runge-Kutta 4 method) students finally obtain a satisfactory result. At our level a closer investigation of numerical methods is not considered necessary: the most important point is that students gain operatively the feeling that numerical methods always have some limits of applicability.

The next step could be the introduction of viscous friction acting on the body. To complete the previous

model, it is sufficient to add a new force, i.e. an additional momentum flow (Figure 9a). For the viscous friction force we assume the standard form

(4)
$$F_{friction} = -b \cdot v(t)$$

where b is a coefficient whose value must be specified or, rather, determined from a comparison of simulation and experimental results previously obtained by the students. The model results show the expected damping effect (Figure 9b).





a) the model is completed with the (viscous) friction force;
b) as a result, the amplitude of the oscillation decreases with time;

c) to explore the effect of the damping coefficient b, students can start a batch of runs with different values of b. An interesting feature is the possibility to have a batch run for different values of a given parameter (Figure 9c): students can compare the predictions of the model for various values of the viscous coefficient b. They appreciate this feature, because they can explore the induced effects and in this way they take a first step toward the understanding of the physical meaning of this physical quantity.

2. Co-ordination with biology and chemistry

My next point is about the role that modeling might assume for the coordination in science teaching at the high school level (i.e. biology, chemistry and physics). First of all, one can ask why advocate a coordinated *approach* to science teaching? The answer to this question can be summarized as follows: students

should have the possibility to appreciate science as a vast, coherent and comprehensible description of natural phenomena. Science teaching therefore must be planned in such a way that students can, in fact, recognize this unity.

Of course biology, chemistry and physics each have their own special aspects: these must be acknowledged, maintained and highlighted. But they also share a core of knowledge, a sort of *transversal conceptual frame* that is common to all scientific fields. I believe that for the students it is of primary importance to recognize these features. The learner must have the possibility to construct step by step a coherent image of natural phenomena⁴.

The main question in our present context is to point out what system dynamics modeling can contribute to this issue. System dynamics modeling allows all three sciences to make explicit use of quantitative methods, to construct dynamical models, and to compare models to reality. System dynamics modeling, which highlights the structure of relationships, also favors the use of analogical reasoning; this can be substantially enhanced adopting the "extensive / intensive" model that we discussed previously, in particular introducing *from the beginning* the pairs entropy / temperature in thermodynamics, amount of substance / chemical potential for the transformations of matter, in such a manner that the conceptual reference frame at the disciplinary level is then completed as shown in the following table:

	Extensive quantity	Intensive quantity	
Hydraulics	Water volume	Pressure	
Electricity	Electric charge	Electrical potential	
Mechanics	Momentum	Velocity	
(translations)			
Thermal processes	Entropy	Temperature	
Chemistry	Amount of substance	Chemical potential	
Table 1 - The conceptual reference frame at the disciplinary level.			

With these tools available, there is a virtually unlimited choice of examples, such as chemical reactions and equilibrium, perturbation of the chemical equilibrium, chemical reactions and energy balances, electrochemistry (Nernst law, Daniell-cell, hydrogen-cell, ...), pH, titration, extraction, osmotic pressure, cell membrane permeability (red blood cells, photoreceptors, neurons, ...) and so on. The most important condition is to work with colleagues who share this approach and who directly or indirectly can refer in their didactical practice to this model.

⁴ For more details see the contribution A titration experiment as an example for a co-ordinated approach in science teaching at high school level presented at the 2005 Girep Seminar in Ljubljana [2] in which a co-ordinated approach based on the introduction of cognitive organizers is discussed.

Students appreciate the coherence of the whole and they feel involved in the conceptual construction. As an illustration, let us consider a (hypothetical) reaction where the substances A and B can change into another under the stoichiometric conditions $3A \leftrightarrow 2B$ and ask, given certain initial conditions, what happens in the system. Here we have an example that stresses the use of analogical reasoning. The idea is to use student's previous knowledge in hydraulics: as shown in the following scheme (Figure 7), the volume of water corresponds to the amount of substances, while the pressure difference corresponds to the chemical potential difference. The reaction will start spontaneously in a certain direction, in such a way that the chemical "driving force" decreases, until it vanishes. In this situation the system has reached equilibrium. Figure 8 shows the model that sums up the previous ideas. In a first situation, the initial conditions are chosen so that at the beginning we have a lot of A and very little of B. Can we predict what will happen in the system? And what would happen if the initial values were different? Say, a lot of B, and only a little of A? The model will allow us to answer these questions and test our ideas

Chemistry		Hydraulics	
$3A \Leftrightarrow 2B$ A, B different substances			
amount of substance		volume of water	
difference of chemical		difference of pressure	
potential			
$\Delta \mu \rightarrow$ Reaction rate		$\Delta p \rightarrow$ Water current	
$\Delta \mu = 0$	equilibrium	$\Delta p = 0$	
Figure 10: The analogies between hydraulics and chemistry.			

Figure 9 shows the model results: we see that a certain quantity of A (upper curve) is transformed into B (lower curve): this occurs because under these initial conditions, the difference of the chemical potential for the reaction "A changes into B" assumes a negative value. We also see that after a certain time, the "driving force" shrinks to zero, so that the reaction rate vanishes as the system has reached equilibrium.

Figure 11 – The model: the amount of substances nA and nB vary when the reaction *rate is different from zero;* this happens when there is a difference of chemical potential. The latter can be computed on the basis of the values of the chemical potentials of the different substances under the initial conditions and must be actualized, during the reaction, according to the instantaneous values of the respective concentrations.







What kind of a process might the plots of figure 10 refer to? At the beginning we have a difference in chemical potential with a positive value: the reaction that will occur is "B changes into A", as we can easily see in the lower plot. After about 3 seconds the system has reached a situation of equilibrium. But now something new happens: there is a sudden increase in the amount of substance A: by an external intervention to the system at this moment a certain quantity of A is added, so that the

equilibrium is perturbed: there is now a surplus of A in the system, so that we again have a difference – with a negative value - in the chemical potential: this means that the reaction "A changes into B" must take place, until a new equilibrium is reached, approximately at the 6 second mark.

At this moment the equilibrium is again disturbed: a certain quantity of B is added to the system by an external intervention and again the system reacts in such a way as to reach equilibrium.



Rather than as an illustration of the particular situation of the *Le Châtelier principle*, the interest of such examples lies in the possibility to introduce, to a certain extent, the factor time i.e. to recover dynamical aspects in chemical and biological processes as well.

3. Evaporation: A real experiment

In this third example I shall demonstrate the use of system dynamics modeling in the interplay between experiment and theory. Real life situations

Figure 13 - Equilibrium and perturbation of the equilibrium.

commonly confront us with a need to alternate between experimental and modeling approaches. Moreover, real applications often lead to models for which analytical solutions do not exist or are hard to come by. With system dynamics modeling not all is lost.

Rather than on the details of this evaporation experiment we will focus our attention on a possible strategy to put students in the condition to create step by step a satisfactory model for the real situation. The experimental situation is the following (Figure 11): a certain quantity of water at room temperature is poured into a porous vessel. The vessel is placed on a balance, in order to measure the mass lost due to evaporation. With a couple of thermometers it is possible to record the temperature inside the vessel as well as the room temperature. A mixer keeps the water temperature as homogeneous as possible. The experimental results are shown in Figure 12. Figure 14 - The apparatus for the evaporation experiment: (a) a vessel of porous material containing water; (b) three thermometers and a balance are connected to an on-line data logger; (c) a mechanical mixer keeps the water temperature as homogeneous as possible.





The modeling strategy consists in the construction of a series of models: step by step, the processes taking place in the real situation are introduced into the model. We start with a vessel containing just water; in the second step we allow water to leave the vessel through a pipe; in the third step, the decrease in water is due to evaporation, while the vessel is still considered thermally insulated; in step 4 we add thermal contact with the surroundings: in other words, we add the conduction of entropy through the wall of the container; in step 5 we consider the real situation: data is added to the model, the simulation results are compared to the experimental results, and missing parameters are determined. The models are structured on three pillars:

- First, the *law of balance of the mass of water* in the vessel: the mass of the water changes as a result of evaporation. The mass flow is not modeled: we take the measured data to specify this quantity.
- Second, the *law of balance of entropy of water*: the entropy of the water in the vessel is not constant because of phase change, mass transport of water, and heating from the vessel.

• Third, the *law of balance of entropy of the vessel:* the entropy of the vessel changes because of heating from the environment, and heating of the water.

Figure 13 shows the model and the related equations: some of the experimental parameters are obtained by matching the simulations results with the measured data. Figure 14 reports the final result.

4. Conclusions and perspectives

I hope you have been able to gain some insight into what students can do, learn, produce and, hopefully, understand. At the beginning of my paper I posed the question: is it possible to involve high school students in modeling activities? I shall begin with a half-answer to this question: Yes, it is, but only under certain conditions. Let me explain.



m(t) = m(t - dt) + (Im) * dt $INIT m = mo$ $INFLOWS:$ $Im = -Im m$ $S(t) = S(t - dt) + (IS conv + IS evap$ $+$ $IS cond) * dt$ $INIT S = spec c water*mo*$ $LOGN(To amb/T ref)$ $INFLOWS:$ $IS conv = Im*spec c water*LOGN(T/Tref)$ $IS evap = Im*LS evap$ $IS cond = -(T-T vessel)/R1$	$C \ vessel = 250 \ \{J/K\}$ $LS \ evap = 0.793e+4\{ \ (J/K)/kg)\}$ $mo = 0.184 \ \{kg\}$ $R = IF \ TIME < 15000 \ THEN \ 928$ $ELSE \ 870 \ \{K2/W\}$ $R1 = 17.4 \ \{K2/W\}$ $Spec \ c \ water = 4184 \ \{J/(K \ kg)\}$ $spec \ s \ water = S/m$ $T = Tref \ *EXP(spec \ s \ water/spec \ c \ water)$ $To \ amb = 294.2 \ \{K\}$ $T \ amb \ m \ K = Tamb \ m+T \ ref$ $T \ m \ K = T \ m+T \ ref$ $T \ ref = 273.15 \ \{K\}$
S vessel(t) = S vessel(t - dt) + (IS cond ext - IS cond) * dt INIT S vessel = C vessel*LOGN(Toamb/T ref) INFLOWS: IS cond ext = -(T vessel-T amb m K)/R OUTFLOWS: IS cond = -(T-T vessel)/R1	T vessel = T ref *EXP(S vessel/C vessel)

Γ



Students like the modeling activities: they are motivated and much more active than usual; they co-operate with each other. From the didactical point of view: the time necessary for the introduction of the basic operative procedures is reasonably short; the modeling activity permits individualized learning. Further, by focusing on the structure which underlies the functional relationships involved in a given situation, modeling also fosters the acquisition of transfer skills and interdisciplinary skills.

The cognitive acts carried out by the students are particularly interesting because the students are required to consider not just singular, isolated notions, but rather a whole network of connections, a veritable conceptual map informed by quantitative aspects. *This is true above all for work-environments which offer a graphic interface.*

However, some conditions must be met. Like all other activities involving new technologies, modeling should not become an end in itself, but rather a tool in the framework of a well defined didactical project. This requires a revision of the contents at the disciplinary level and also, perhaps, of some of the teaching objectives. Therefore we have to:

- prepare and develop suitable didactical materials;
- provide adequate teacher training;
- set up interdisciplinary discussion groups to promote and ensure substantial co-ordination with the other scientific disciplines and with mathematics.

Let me just close, then, by quoting Arnold Arons [3]: "Wider understanding of science will be achieved only by giving students a chance to synthesize experience and thought into knowledge and understanding." I am convinced that modeling can be a useful tool to this end..

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Challenges and Opportunities in computational modeling

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Abstract

In this paper I explore issues in the construction of computational models to support the learning of physics, using a number of different tools. When teachers and children express and explore their understanding of a topic in this new medium, some new issues arise and some older issues are thrown into sharper focus. Successful periods of use will need: to define tasks that guide subtly without constraining possible outcomes too tightly; to allow teachers and their students to recognize partial and complete success; to illuminate the process of modeling. Within this framework I illustrate how the use of these tools opens up new opportunities and presents new challenges: Both for those who learn physics and for all those who support that endeavor. I will draw on experiences in working with children from 10 to 19 years old, teachers and pre-service teachers. Children's competences vary across this ability range, and the kinds of thinking to be represented also vary. I show how a variety of computational tools can be used to enable pupils and teachers to work with these variations. In conclusion I indicate where I think there is still further work to be done: in elucidating what children gain from these activities; in the design of computational modeling environments; and in the impact on the teaching of physics.

Engagement

To engage children in computational modeling is to give them an enhanced chance to theorize - by giving them carefully shaped building blocks to assemble in a place where this assemblage is open to inspection and commentary by their peers and teachers. Giving children these opportunities in physics lessons is in many ways only equivalent to allowing children to draw in art lessons - they engage in some practice of physics in order to better appreciate the nature of physics (both what and how it represents - rather than just engaging in the equivalent of art appreciation classes). The purpose of these assemblages is usually not too difficult to communicate in outline in the classroom, although the finer detail and the comparison of differing constructions might well be. Children assemble the blocks to produce a dynamic artifact that mimics some aspects of nature's behavior. They invent a world that has some important similarities to the everyday world around them. Their invented world will also have some differences - for a start it will necessarily be somewhat stripped down, paying attention to only a few of the aspects of the real world. Using computer based tools can make these models more

explicit, inspect-able and so more public than in some other cases where "models" are used in science lessons.



Figure 1: A completed model

How they go about constructing such worlds is a complex process and the purpose of this paper is to share some thinking about how this process might be smoothed and about how one might evaluate the outcomes of such constructions. I do not attempt to argue strongly for the inclusion of modeling: rather here I explore how one might go about improving the experience - exploring some didactical developments that might support modeling in the classrooms, drawing particularly on recent work with younger children (11-16 years old).

Clarifications

First a few clarifications; even given that one is working with computational tools. There is a spectrum of different kinds of activity that can be engaged in with tools that allow you to express your thoughts on the computer. Here I am interested in the deepest aspects of the scientific endeavor, where one engages with the rules that are our current best guess for the underpinnings of the workings of the universe. So I want children to be able to write, read and modify such rules in their invented worlds and then see how well these worlds mimic the working of the real world. This ability to alter the rules is what I take to be modeling, as opposed to simulating or animating; both of which are briefly characterized in the diagram above.

Thinking with tools

There are a range of more or less appropriate tools available for modeling that fall into two groups that are at least pedagogically helpful as ways in which thinking in science can be described: as thinking with variables and the relationships between them and as thinking with objects and their properties.



Examples of modeling tools from both groups can found that are suitable

Figure 2: A range of different uses for computational tools

Coach, VnR, InsightOnP: WorldMaker, StarLogo, StageCast, AgentSheets, Squeak. Even when modeling with these tools there are at least three ways that the tools can be used. Teachers might use the modeling tool with children in exploratory mode, where sharing a built model with them is simply a way of exposing their thinking to the children explicitly. As one can see all of the functional parts of the dynamic representation, one is more likely to be able to see how they interact and why the whole system behaves as it does. The tool can also be used metaphorically, rather than directly. Here past experiences with the tool are used by teacher or child as elements in constructing an explanation, rather than using the computer modeling tool directly to create a fully functioning model of that which is under discussion. Finally, and my main focus here, the computer modeling tool can be used expressively, where children construct a model to express their own thinking about a topic, by writing rules that drive their invented world.



Figure 3: Two styles of thinking in the sciences

Managing learning with tools

The remainder of this paper will be concerned with managing this task: Children build dynamic models of invented worlds that mimic the natural world in some important ways and recognize the importance of what they have done for their understanding of science. After considering the challenges in selecting an appropriate task, I go on to consider how one might recognize appropriate performances, choose learning outcomes and how, over a longer time-scale, one might best think about children appropriating the modeling tool. For simplicity all of the illustrations here are drawn from work with a single modeling tool, VnR, but I have worked with the full range of tools and age groups indicated, and believe that the pedagogical conclusions hold irrespective of the particular tool, and small adjustments to the didactical implications see the teacher through in these modified situations. Setting children to produce a model of a phenomenon requires careful thinking and wise choices. The target must be both worthwhile, with success being both intelligible and rewarding, and yet accessible. The end point, the completed model, may be immediately visible to children, or there may be several steps on the way. One essential component of a successfully chosen task is that there are choices to be made. If one provides a recipe for children to follow carefully then much of the value is lost: programming children to program computers is useless. The children are no longer expressing their own thoughts; they are simply parroting the thoughts of the teacher. So there must be some choice in pathways and some choice in how the journey is made. This will be partially fixed by the tool chosen, and partially by the structure and nature of the topic, but there will still be choices. The paths chosen may be featureless or feature rich - so the modeler knowing where they are and where they are heading for will be more or less difficult depending on the terrain. With such variations in the landscape it is important to consider the transport made available. This needs to present an appropriate balance of affordances and resistances, so that the user is kept in touch with the landscape, rather than being whisked effortlessly over it, and yet does not become so bogged down in making progress that they simply cannot see a way forward, or lose all strategic awareness. And there is a further constraint - the means of transport should not be unique to the task: in modeling one should be making progress in thinking about the general processes as well as the particular circumstance. In modeling the tendency and aim of science to provide unified explanations can be rendered explicit, so we should actively plan for this possibility. That is, one should emphasize the powerful and deep insights central to the topics in which the models are located, rather than rely on ad-hoc relationships that serve the particular situation but which are not of wider significance. Even in the most barren of landscapes, and in any case sometimes also supportive in more richly featured landscapes, one can artificially place markers to indicate progress - milestones. These features are under the control of the teacher, and are somewhat independent of topic or tool, save that they must be expressed in terms that link to these two, and so can be strategically placed. One way in which these placements are helpful is in helping to delineate progress. Children and their teachers need to know if they are heading off down the right line or making off up the wrong tracks. So in many modeling tasks it is useful to have a series of markers, perhaps themselves milestones, that indicate partial success as steps on the way to the final model. In many modeling tools it is useful to choose the first milestones so that they result in some simple to understand reaction on the part of the tool, even if that is not central to understanding the phenomena being modeled - in mountaineering the most direct route is rarely the most advisable, particularly for the less experienced or those in need of moderate challenges only. As an example of an early milestone: in modeling an ecosystem or the spread of a virus getting the objects to move in appropriate ways gives immediate feedback and makes students confident that they are in control of the computer and not the other way around. Getting things to move is a rather simple success: but how are children to judge the success, or partial success of their models? I suggest that there are two rather different, but equally important facets. The first is mimicry: the outputs from the model show similar behaviors to the phenomenon. This itself is not simple: there will necessarily be aspects of nature not represented in the model and so there will be necessary imaginative steps in relating the outputs from the model to what is seen or remembered in nature. But similarity of behavior is not enough - there are many things that are statistically related yet not causally connected (the standard example of storks and childbirth comes to mind in the context of the Netherlands) and in teaching physics one would want to emphasize the difference. So one would want to have some kind of structural elements within the model that express some of the deep and important

statements in the appropriate truths in the areas of physics relevant to the model. (Schecker named these power tools). For example in a description of electric circuits one would expect to find the relationship $I = \Delta Q/\Delta t$. These statements should not be too austere: one might be able to write all of the relationships in physics on the back of a postage stamp (size chosen wisely), but these may not be too intelligible without courteous elaboration and translation. To exemplify this consider the following models of radioactive decay chains:



Figure 4: A stripped down model of a radioactive decay chain

The simplest models, for us laying bare the essence of independence of the behavior of the nuclei - that the rate of decay depends only on the number of nuclei themselves, may be simple, but indigestible for those just coming to an understanding of these relationships. The more elaborated model shown below, that makes the steps more explicit, also makes the whole more intelligible.



Figure 5: A more explicit model of a radioactive decay chain

Here the intermediate steps and connections are shown, spelling out the kind and nature of the relationships. These connections are repeated, showing that the same thinking serves us twice. This repeated use of patterns in thinking is characteristic of physics and of modeling in the sciences.



Figure 6: Three of the important patterns of thinking in the sciences

Important prototypes

This is a trivial example of such repetition, but there are simple patterns in the thinking here, represented graphically, which do turn up in many different models. As these turn up often, they ought to be appropriately highlighted in the children's models, to bring out the significance, as the children will not have the breath of experience to recognize the importance of these elements. Here are three important patterns, representing thinking that is pervasive in the sciences.

Whilst adding and finding differences are rather straightforward to explain, the difference between multiplying and adding is somewhat more subtle in this semi-quantitative modeling tool, where the absolute magnitudes of the output values cannot be easily compared. So one cannot distinguish between addition and multiplication of two inputs larger than unity by seeing which of the outputs grows fastest. Instead one needs to consider what output is desired, in terms of either the referents of the variables (emphasizing the understanding of the structural elements of the models again), or in terms of the required mimicry of that section of the model: multiplication is appropriate if the output must fall to zero as soon as either input falls to zero, otherwise one uses addition. Distinguishing between cumulative and proportional relationships is another area where commonality of pattern may help to overcome children's difficulties. One might also engage children's enactive imagination: in the case of proportionality an evocative re-description for children is that "one variable follows another" or that the "input variables

tell the output variable what to be". Similar courteous re-descriptions can be thought of for the rate or cumulative relationship. Here one can say that "the input variable tells the output variable how to change" or that "one variable grows another". Choosing to relate two variables in one of these ways rather than the other changes a model in rather fundamental ways, so appreciating the difference is very important. In fact to become a competent modeler one needs to have access to a limited range of structures but to be able to combine them in different ways in order to be able to represent varying phenomena. Here is a somewhat complicated model, at least for children at the lower end of the target age range and yet it is constructed only of the few combinations that are sketched above. So the working of the whole model can be understood in terms of these enactive prototype interactions.



Figure 7: A model containing four enactive steps

In fact one can easily encode a series of models in terms of the connections made to show how the modelers access this range of structures in their models as they work on a particular challenge. There are some iconic simple models however, that rely on only a subset of these relationships. Here, as with the nuclear decay models one ought to beware of the alienating effect of the stark simplicity. Those schooled in physics may appreciate the simplicity in simple harmonic motion: others may need more careful aesthetic education. However this kind of model is worth working towards as it does emphasize the "power laws", and the value of focusing on them. To support children becoming more skilful with modeling tools, I think that we ought to concentrate on enabling children to appropriate these simple enactive prototype interactions as building blocks. These will then serve as chunks of meaning which can be assembled and reassembled to describe new situations, based on an understanding of what they did and had done to them in the situations in which they have already been used. In this way the readability, and so the intelligibility of models can be enhanced. This model can be split into four parts, each of which has an intelligible action associated with it. In

this way the whole model gains plausibility, because each of the parts are intelligible.

Nevertheless the behavior of the whole is more than the sum of the parts: few children will be able to predict how the number of organisms will change. This aggregate behavior arises from the interplay of the behaviors of the simple interacting parts, which are known about as individual behaviors. In this kind of modeling tool (VnR) the following seem to be a complete set of such interactions.: summing, finding a difference, multiplying, sharing out, growing from a start, and changing after a critical value. However both the descriptions and this list are subject to revision: one needs to find more and more felicitous ways to characterize these building blocks, and this requires yet more time spent with children building models. I think that there is not currently enough practice to be very close to a final set of descriptions in which one can have enormous confidence. However, I do not think we should be too downcast: it is a rather subtle piece of describing that is being attempted.



Figure 8: A model with the four elements identified

There are analogous prototypes for the other kind of modeling tool (OnP): again a provisional list (Provided here to show that the same approach to learning can work in both kinds of tools). These are based on the actions of an individual, which takes the place of the relationship in the VnR models, as the enactor; so preserving the link to the enactive basis of the interpretation of modeling tools.

Successful modeling

A successful modeler will need to connect together these enactive blocks to re-describe a phenomenon in a way that produces a computational mimic of the phenomenon. To do so in a fruitful way they will need to make preferential use of the deep relationships in the topic. So a competent modeler will need to see patters, aim for simplicity and think about the essence of

things. None of these rather high-level attributes are strongly tool-based, but will of course depend on the tools to hand. With these descriptors of a successful modeler in place, looking back over the account of supporting modeling that I have provided, here is a summary of the challenges in developing a pedagogy of modeling:

- Tasks: Learning how to set appropriately challenging tasks
- Transportation: Considering how children are to get from their starting point to the successful completion of the task
- Paths: Working out by what routes the children might progress with the transport available
- Milestones: Placing recognizable markers along the paths to guide, constrain and encourage

Finally there is the issue of assessment: how one might recognize and value what the children are doing in building their models. This is the topic for another paper, but the pedagogic tools developed above can be turned to formative assessment purposes as well, perhaps particularly working on developing informative milestones.

Looking forward

There will also be developments in the tools. I think that these should also be driven by the analysis of learning presented by this paper, alongside what developers can see to be computationally possible. Particular attention should be paid to the appropriation of prototypes, I believe, as the best way of supporting low density users of such tools to think helpfully about the phenomena which they are trying to represent. Modeling presents new



Figure 9: Useful building blocks for VnR style tools

opportunities as well as these challenges. In particular it enables children to make things, to engage a kind of creativity that may only be engaged less directly using existing approaches. Children can also make their ideas plain without having to refract everything through the prism of language; computers should be seen primarily as a representation tool, and so an expressive medium, I believe. Finally the enforced simplicity cuts to the core of doing physics, and is likely to throw up new didactic possibilities as subject knowledge is reconsidered in the light of these new tools.

A few very useful rules



Wander about quite slowly - at about half speed.

Look to my right. If there is some grass, then eat it, about half the time.

If you are next to another rabbit, then breed. About 1 time in 5 this will produce a new rabit

If you are next to sick rabbit, then about 1 time in 10, you get sick.

You have a 5% chance of dying – about 1 time in 20.

Figure 10: Useful building blocks for OnP style toots

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System Dynamics Modeling in Fluids, Electricity, Heat, and Motion Examples, Practical Experience, and Philosophy

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Abstract

System dynamics provides for a general and user friendly approach to the modeling of dynamical systems, irrespective of the field of application. Although SD modeling – as it is practiced in areas from economics to ecology – is hardly known in physics and physics education, physics is particularly suited to the methodologies and tools of system dynamics and systems thinking.

In this talk, examples of modeling and the direct comparison to experimental data will be discussed. Examples range from simple (draining of a tank, heating of a body, charging capacitors, muffin cups falling in air) to larger case studies (the circulatory system of mammals, thermoelectric cooling). The examples have been developed for and used in introductory university physics for engineering students.

As described here, SD modeling is an element of an integrated learning environment where experiments, modeling, and simulation blend with the learning of the formal aspects of our science. The talk describes practical experience gained with this type of learning environment in recent years.

Finally, it will be demonstrated that SD modeling suggests how the use of analogical reasoning can be made into a major tool for learning an abstract field such as physics. It will be shown that the analogies used in fluids, electricity, heat, and motion are based upon fundamental human reasoning. Evidence of this reasoning is found in conceptual metaphors used by humans in everyday life.

1 Introduction

Modeling is the name of the game in physics, and Newton was the first system dynamicist. If we look at modeling in physics at this granular level, we do not really need a conference on modeling in physics (or physics education). Whenever we do physics, we model. So what else is there to say?

It does make sense, however, to look at modeling in physics more specifically from at least two points of view. One, there are different types of models and, consequently, there are different ways of modeling. Second, modeling is not dealt with explicitly in most of our classrooms, so it will be worthwhile to discuss methods that let us deal with modeling in an explicit form in physics education—even at a very early stage in the education of young people.

System dynamics modeling is special in some well defined ways and it is easy and powerful enough to lend itself to explicit modeling in the classroom (traditional, lab, or studio). In fact, it is so easy and powerful that it may well be one of the best tools and methods to effectively integrate modeling with experimental activities in a way that reflects important aspects of the scientific method. Again, tools and methods are applicable even at an early stage of the educational enterprise.

The Origins of System Dynamics Modeling

System dynamics was not developed with physics in mind. In the US, most practitioners of what has become known as system dynamics call themselves members of the social sciences. True, system dynamics, as it was developed by Jay Forrester, has its roots in control engineering, cybernetics, and systems science in general—which in turn have their roots in early systems science in biology and physics. But today, most of the activity going on in system dynamics proper is indeed found in the social sciences, and maybe in environmental science. Donella Meadows wrote in 1991 (Meadows, 1991, p.1):

"System dynamics is a set of techniques for thinking and computer modeling that helps its practitioners begin to understand complex systems—systems such as the human body or the national economy or the earth's climate. Systems tools help us keep track of multiple interconnections; they help us see things whole."

An Example: Natural Gas Usage in the USA

Here is an example of a diagram representing the visual elements of a model of natural gas usage in the US during the 20th century (Roberts et al., 1983, Chapter 23); see Fig.1. Note the main structures outlined in solid color. It represents two laws of balance, one for the quantity of gas believed to be (left Undiscovered) in the Earth's crust, and for the Reserves, i.e., the quantity of gas discovered and placed in the "virtual container" of known reserves. Laws of balance are first order differential equations (initial value problems). The first storage element is depleted by the process of discovery, the second is replenished by this process, and depleted by usage (which basically is the same as the production rate). The quantity labeled Discovery is the rate that "moves" gas from the one container to another. The process quantities Discovery and Usage are determined by feedback relations are so-called constitutive relations that express the differences and variability found in various systems. Laws of

balance, in contrast, are always of the same form; they are the generic laws of a model.



Fig. 1: A model representing the use of natural gas. Note the different elements. Rectangles (called stocks) represent stored quantities, pipelines (called flows) symbolize processes (flows or production rates). Combinations of stocks and flow in general represent laws of balance (solid color at the center of the diagram). There is a stock-flow structure which is not a law of balance. The relation between Rate of Change of Price and Price is a simple integrator. The relation that matters is the "inductive" law that determines a rate of change of price based on some "pressures." The process quantities are determined by feedback relations expressed by circles (variables) and thin connectors. See Fuchs (2002), CBT Chapter 2, p. 96-115.

Note that there is another structure made up of a storage symbol (Price) and a flow symbol (Rate of Change of Price). This is not a law of balance. Rather, nature—or economics—determines the rate of change of Price. (The structure made up of stock and flow serves to integrate the rate of change to yield the proper quantity.) We are accustomed to thinking of inflation as the result of inflationary pressure which determines how fast prices change. In physics, such a relation is equivalent to an inductive phenomenon (a pressure difference determines the rate of change of a current).

A model of the type shown in Fig.1 can be simulated, and the simulation results can be compared to data. The comparison yields important information about the quality of the ideas underlying the model (Fig.2).



Fig. 2: An example of a simulation of the model shown in Fig.1, and a comparison of the simulation (rounded curves) with data (jagged curves). Discovery rates and usage rates are shown. After about 1980, usage and production rates start to deviate.

In summary, system dynamics modeling applies a graphical approach to building models of dynamical systems by combining the relations we perceive to hold in such systems. It makes use of very few structures which are projected onto virtually any type of dynamical system and its processes, i.e., it makes strong use of analogical reasoning. Mathematically speaking, the models created are initial value problems of spatially uniform elements.

SD Modeling Tools

We use modern graphically oriented tools to produce evolution equations; the tool should make use of containers and flows (and production rates), and auxiliary quantities (and integrators).

There are several programs available that implement the SD approach. The earliest tool that included a full-fledged graphical interface was Stella. A similar tool sporting somewhat more sophisticated numerical methods is Berkeley Madonna.

2 Examples of SD models of physical processes

Physical systems and processes can certainly be part of the complex dynamical systems Donella Meadows talked about (see Section 1, Meadows, 1991). Moreover, they provide us with some of the simplest systems upon which a successful introduction to SD modeling and systems science can be based. The practice of SD modeling, together with the development of continuum physics (Fuchs, 1996) and the didactic approach to physics developed in Karlsruhe (see Herrmann, 1991-1995), inspired me to look for a generalized, "system dynamics friendly" representation of basic physical processes, and to use physics to guide our view of the general structure of system dynamics models (Fuchs, 2002a). In the following, I shall present some examples of models and their comparison to experiments. The applications have been developed for a first year university physics course for engineering students.

Two Communicating Oil Containers

Communicating fluid containers represent one of the simplest and most basic systems that can teach us much about the modeling of dynamical processes (Fig.3).



Fig. 3: Two communicating oil tanks (top left), data of the equilibration of levels (top right), situation sketch (bottom left) and SD model diagram (bottom right).

The diagram of a system dynamics model of two communicating fluid tanks is built around the laws of balance of fluid volumes in the two tanks (Fig.3, bottom right). The volumes of fluid change as a result of the flow of oil from the container having a higher oil level to the one having a lower level. The flow is assumed to depend upon the difference of fluid levels. In the simplest case, the flow is proportional to this difference. Using these assumptions, the model yields close to perfect agreement with experimental data.

A Comparison of Equilibration Processes in Fluids, Electricity, Heat, and Motion

The simple structure of a model of communicating oil containers can be transferred to all the other basic physics processes (Fig.4). The equilibration of fluid levels, velocities (translational motion), voltages (electricity), and temperatures (thermal phenomena) can be explained using analogous structures. In the thermal case, there is a problem though (see the next sub-section).

Entropy Transfer and Entropy Production

The comparison of simulations and experimental data is successful for the examples shown in Fig.4, with the exception of the model for thermal equilibration. This model applies to a system where two liquids at different temperatures are in thermal contact. The liquids have constant entropy capacitances (such as in the case of glycol). We know from experience that the final temperature reached by two equal amounts of glycol is higher than the average of the initial temperatures. The model, in contrast, predicts the average value of the initial temperatures. The reason for the limited success of the simple model in Fig.4 (bottom right) has to do with the fact that we have neglected entropy production due to dissipation. As in all conductive transfers, energy is dissipated and entropy is produced as a result. Whereas entropy production does not influence the balance of amounts of liquids, charge, or momentum, it certainly changes the balance of entropy in entropy transfer between two bodies in thermal contact (Fig.5). More entropy flows into the colder body than leaves the warmer one. In conductive entropy transfer, energy is released and dissipated. Entropy production is a result of this dissipation.



Fig. 4: The phenomena of the equilibration of fluid levels, voltages, velocities, and temperatures can be explained with the help of analogous model structures.


Fig. 5: If entropy flows conductively from one entropy storage unit to another, entropy is produced (think of a thermal resistor between the two storage units). Here, a stock has been introduced to represent a node (junction) that does not store entropy. The junction rule relates the entropy current out of storage unit 1 (IS), the entropy production rate (Pi_S), and the entropy current into the second storage unit (IS_2). The entropy production rate is determined by the ratio of the dissipation rate and the (lower) temperature. The dissipation rate equals the rate at which energy is released in the fall of entropy from T1 to T2 (this quantity is calculated from Carnot's relation).

A comparison of a model of two bodies of water in thermal contact inside an insulated double container with real data shows that the inclusion of entropy production makes the model successful (Fig.6). If we turn off the effect of entropy production in this model, there is a small but noticeable difference between simulation results and reality.



Fig. 6: Model, simulation, and data, for two bodies of water in thermal contact inside an insulated container having two compartments separated by a thin metal wall. The model makes use of the irreversibility of conductive entropy transfer. Here, the expressions for the entropy-temperature relation have been adjusted to the case of water (constant specific heat means an exponential Ts-relation).

Inductive Effects in Fluid Flow: Blood in the Aorta

Pressure and blood flow change rhythmically inside the aorta of a sheep. A fairly successful model can be built by using the structure of Fig.3. The aorta is divided into small sections (elements) and for each element the pressure is calculated from the volume of blood stored. Blood flow between two adjacent elements results from the pressure difference between these two parts. At one end we have the heart as a pump, at the other end we add blood flow through a long pipe symbolizing the vessels through the body. We get fair agreement between simulated and measured blood pressure, but there is an important difference between model and reality for blood flow.

In reality, there is a small back-flow of blood in the aorta (negative volume currents) for part of a cardiac cycle. This phenomenon cannot be explained with the model structures used so far. Combinations of RC elements do not lead to oscillating currents.

The solution is found by adding the effect of hydraulic induction to the model (between each element of the aorta, Fig.7). A part of the pressure difference between two elements leads to time rates of change of the currents of blood. The SD structure that deals with this phenomenon is similar to the combination of stock and flow used to calculate changing prices in an economic model (see Fig.1).



Fig. 7: If inductive (inertial) effects are included in the model of blood flow, the current is obtained from integrating the rate of change of the current (lower stock-flow relation). The rate of change of the current results from the inductive pressure difference which is the difference between the (driving) capacitive pressure difference (delta $P_Ao_1 - delta_P_Ao_2$) and the resistive pressure difference (equal to $R_Ao\cdot IV_1$ for laminar flow). Even though the comparison between data (blue) and simulation results (red) is less than perfect, we get the desired result of oscillating currents.

Thermoelectricity: A Peltier Device

To conclude this list of examples, I will discuss a simple model of a thermoelectric Peltier device. Such a device can be run as a generator (heat engine) or as a heat pump. Seen from a distance, the device appears to operate as follows. There is always a hot side and a cold side, and a side that is at a high electric level whereas the other side is at a low level; in other words, there are thermal and electrical "tensions" or driving forces across the device. Obviously then, currents of entropy and of charge go through the device from one side to the other. Observations show that a temperature difference sets up an electric driving force (thermoelectric voltage). If we model the electric properties as two capacitors representing the sides of the Peltier device at high and at low potential, respectively, there must also be something like a generator element between the capacitors. The electric phenomena can therefore be models as in Fig.4 (bottom left) with an additional thermoelectric voltage driving the current between the capacitors. The thermal system is made up of two thermal capacitors (entropy storage elements) with two types of entropy transport: One, the standard conductive flow from hot to cold sides and two, a forced current which is



Fig. 8: Model structure of a Peltier device. Thermal and electrical aspects are modeled as seen in previous examples (Fig.4 and Fig.5). What makes the device work are the couplings between the two phenomena. Note the relation between electric current and (Peltier) entropy current, temperature difference and thermoelectric voltage, and conductive flows and entropy production.

coupled to the electric current (Peltier effect). Without this current we cannot explain how one side of the device can become cold at the expense

of the other. The SD model of the thermal aspects therefore looks like the model in Fig.5 with an additional—non-dissipative—entropy current (Fig.8).

The thermal and the electric side are coupled; there are three feedbacks. First, the temperature difference produces the thermoelectric voltage which is part of the drive of the electric current between the electric capacitors. Second, the additional (Peltier) entropy current is proportional to the electric current. Third, the electric current leads to an additional entropy production—in addition to that resulting from entropy conduction.

The factors relating temperature difference and thermoelectric voltage one the one hand, and between electric current and (Peltier) entropy current on the other, must be equal. It is interesting to note that we can prove this based on continuum physics arguments (Fuchs, 2002b). If we calculate energy relations we see that the balance of energy will be violated if the Seebeck and Peltier coefficients are not equal.

Structure of SD Models in Physics

So what can we learn from the examples about the structure of system dynamics models of physical processes? And what does this tell us about how humans "see" nature? The second question will be dealt with in Section 4.

The models have at their centers combinations of stocks and flows which are expressions of laws of balance for quantities such as fluid volume, electric charge, entropy, momentum, angular momentum (for rotation), and amount of substance (for chemical processes). These quantities accumulate, and they can be changed as a result of flow and production processes.

Processes are related to differences (of potentials). We can interpret potential differences as driving forces that lead to flows, production rates, and changes of flows. These differences are in turn produced by differences in storage elements and pumps (in a generalized sense; a battery is a pump for electricity).

When quantities flow through a difference, energy is released. The energy released is used to drive other processes (set up other differences), dissipated, and/or stored.

The image emerging here closely corresponds to what we know from continuum physics. System dynamics models of the type presented above are spatially uniform versions of continuum models. They lead to a unified presentation of the most basic physical processes of the following form (Fuchs, 1996, p. 2; see also Fuchs, 1997a, 1997b, 1998):

> First, we have to agree on which physical quantities we are going to use as the fundamental or primitive ones; on their basis other quantities are defined, and laws are expressed with their help. Second, there are the fundamental laws of balance of the quantities which are exchanged in processes, such as momentum,

charge, or amount of substance; we call these quantities substance-like. Third, we need particular laws governing the behavior of, or distinguishing between, different bodies; these laws are called constitutive relations. Last but not least, we need a means of relating different types of physical phenomena. The tool which permits us to do this is energy. We use the energy principle, i.e., the law which expresses our belief that there is a conserved quantity which appears in all phenomena, and which has a particular relationship with each of the types of processes.

3 Modeling in an integrated learning environment

The examples of system dynamics models and the experiments they are based upon were developed in and for an integrated learning environment. Modeling activities are integrated with experimental work and form the backbone of the learning process. The areas covered are taken from the physics of dynamical systems (fluids, electricity, heat, substances, and motion). This learning environment is used in first year university courses for engineering students. One of the aims is to confront the students with aspects of systems science.

The Modeling-Experimental Bi-cycle

The interaction of modeling with experimenting can be symbolized as a bi-cycle (Fig.9). Each cycle represents a sequence of activities having to do either with modeling (analysis, model construction, simulation) or experimenting (planning, building, measuring, data processing). When modeling leads to a simulation result, and experimenting yields sets of data, these results can be compared. The comparison typically suggests how to proceed with further work. We may want to improve upon the model, perform more and other experiments, or both. In other words, the bi-cycle is a visual model for a form of the scientific method.



Fig. 9: Bi-cycle representing modeling (left) and experimenting (right). The interaction of these activities is symbolized by the cube at the center.

Note that in this relatively standard and traditional view of the scientific method, two important elements are missing. Where do good questions for investigation and hypotheses for models come from? The problem of hypotheses will be discussed in Section 4.

Contents, Tools, and Materials of the Integrated Learning Environment

Choosing to base a physics course on the bi-cycle in general, and on the modeling of dynamical processes in particular, will surely lead to changes in a typical introductory physics course. The decisions made here lead to a course that is based upon the continuum physics paradigm (Fuchs, 1997a) and integrates physics with systems science (Fuchs, 2002a). The models presented are part of a curriculum that is best described as leading to applications in chemical and energy engineering, environmental science, biology and medicine. These fields provide us with important and fascinating systems that are different from traditional applications in physics in their relative complexity. They are worthy of an approach that leads learners toward an appreciation of dynamical systems and systems science. Typically I work on most of the ten subjects shown in Table 1 in a 12 credit first year course for engineering students. An important aspect of the learning environment is the inclusion of case studies with each of the subjects. Case studies motivate the physics, and they allow me to stress methodological aspects such as stressing the scientific method by going repeatedly through the bi-cycle (Fig.9).

	Subject	Case Study
1	Storage and flow of fluids	The systemic blood flow of
		mammals
2	Electric processes and energy	Supporting batteries by
		superconductors
3	The dynamics of heat	Thermoelectric cooling
4	Chemical processes	Stratospheric ozone
5	Induction, oscillations, waves	Diodes and chaos
6	Rotational mechanics	Keeping time: Mechanical clocks
7	Translational motion	Parking space craft at Lagrange
		points
8	Heat, fluids, and radiation	Atmosphere, radiation, and winds
9	Flow systems	Latent heat storage
10	Dynamical systems	The inverted pendulum

Table 1: Themes and Case Studies

The materials that support the learning environment are made up of texts, movies and data presenting experiments, models, guides, problem sets, and more. They are implemented on DVD and can be accessed through a standard browser.

A number of tools are needed to work actively on physics problems and case studies. They include data acquisition, spreadsheet software, system dynamics modeling programs, and the Internet.

Experience with the Integrated Learning Environment

The experience gained over the last four to five years makes me hopeful that activity based learning of physics in an integrated studio environment is a viable alternative to standard physics courses based on the lecture-recitation-lab approach. Dynamical modeling takes a larger role than in any other studio course I am aware of. It has by now become an indispensable element in a course that allows students to work on real-life applications (in fact, allows them to let learning be guided by these applications). Intuition for and qualitative understanding of the most important physical principles are developed quite naturally as a consequence of the activities. Students consistently remark that they like the systems science approach based on the explicit use of analogies.

4 Imagination, figurative thought, and SD modeling

We tend to believe that propositions in physics are basically independent of the human mind. They are out there in the world, ready to be "found" by scientists. In other words, they are objective and "true" representations of the (material) world existing outside of us. One consequence of this is that physicists are inclined to accept physical theories in the form in which they were developed in their time. They seem to forget that physical theories are models, that physics is a model. Theories are a creation of the human mind that makes use of all the figurative forms of thought upon which human reasoning was built through evolutionary history.

Recent work in cognitive science gives us a radically different picture. Human reasoning is figurative—rooted in imaginative structures through and through (Johnson, 1987; Gibbs, 1994). Some of the most interesting work on figurative structures has been done in cognitive linguistics (Lakoff and Johnson, 1980, 1999; Lakoff, 1987; Gibbs, 1994). This research demonstrates how we can make use of human language by investigating conceptual metaphors—to understand how humans "see" the physical world around them. Recently, I have identified some of these structures (Fuchs, 2005). Interestingly, they have much in common with models of physical processes found in continuum physics. To some degree, the metaphors are built into the system dynamics tools that were developed in recent decades.

Above, I described the bi-cycle as a standard model of scientific methods (see Fig.9) and mentioned that it lacks in two important respects. Two questions remain unanswered: How do people come up with good questions for investigations, and where do ideas for models come from? Our typical reaction to these questions is "…and then Einstein (Newton,

Maxwell...) had an idea..." In this section, I would like to show that the human power of generating ideas and hypotheses for models (of physical processes) stems from imaginative structures that are visible in conceptual metaphors with which all of us describe nature.

Where do ideas for models come from?

Generating ideas for hypotheses is thought to be a highly creative act. Since we are moving in largely uncharted territory, we often attribute this type of creativity to only a few special individuals. Based on the theory of cognitive tools (Egan, 1988, 1997, 2005) I would like to argue that every human has access to tools that allow them to be creative in the sciences in an important sense. We can specify acts of thinking and working much like in the case of modeling and experimenting that allow us to come up with good questions and ideas for models. Therefore, I have extended the bi-cycle of Fig.9 to a quadruple-cycle (Fig.10). Two new cycles symbolize some (fairly) concrete steps we can take when confronted with the "soft" tasks of generating good questions (motivation) and ideas for hypotheses. I identify the acts with two cognitive tools described by Egan (2005) which he calls mythic and romantic thinking. Suffice to say that Egan has concrete suggestions for what constitutes these forms of human thought.



Fig. 10: The bi-cycle of Fig.9 is extended to a quadruple cycle by including the cognitive tools of mythic and romantic thinking for answering questions regarding the generation of hypotheses and questions.

In my model, the generation of ideas and hypotheses (the cycle H in Fig.10) is associated with mythic thinking. Mythic societies are those that use oral language only. Orality leads to some interesting cognitive tools that demonstrate aspects of imaginative structures of the human mind such as metaphoric reasoning (Ong, 1982). This has led me to a search of

conceptual metaphoric structures in physics that might tell us where to look for the roots of ideas and hypotheses for physical processes.

Conceptual Metaphors

Metaphors are traditionally called embellishments of language used by gifted writers or speakers. We go so far as to think of metaphor as the antithesis to "true" literal expressions: Metaphor is "not real" and even "lies." Recent work in cognitive linguistics informs us that metaphor is not so much a linguistic expression than a form of thought—in fact, a fundamental imaginative structure upon which human reasoning is based (see Kövecses, 2005, for a recent textbook on conceptual metaphor). A conceptual metaphor such as Organizations are Plants has many (linguistic and other) expressions such as "The company grew strongly," "The branches of the firm," or "Their recent efforts bore fruit," etc. Conceptual metaphors have entailments which represent examples of how we reason based on the metaphoric structure. Conceptual metaphors are essentially unconscious, and when they are made conscious we often do not recognize them as such. They lead to such inconspicuous expressions as "The temperature is high," "Electricity is flowing," or "The force of water."

The Gestalt of Physical Processes

My personal experience with students' reasoning and research into the origins of thermodynamics (Fuchs, 1996) lead me to believe that we experience (classes of) physical processes as gestalts. Experience with collectives of phenomena that lead to a perception (such as phenomena having to do with fluids, or with hot and cold) are abstracted so that they become a perceptual gestalt—a gestalt of fluid substances, of electricity, of heat, of chemicals, or of motion (see Fuchs, 2005).

Gestalts are wholes that are more than the sum of possible parts. (The term gestalt can mean "pattern" or "configuration." In gestalt psychology it is emphasized that the whole of anything is different from the sum of its parts: Organisms tend to perceive complete patterns or configurations rather than bits and pieces. See King and Wertheimer, 2004) Gestalts are normally undifferentiated. However, when we ask people to describe their experiences of the sum-total of a class of perceptions (such as thermal ones), their words tell us that we do see aspects in a gestalt—the gestalt appears to be weakly differentiated. Most interesting for our purpose here is that the aspects associated with different gestalts seem to be basically the same. And this holds for physical as well as completely non-physical examples (consider the concept of pain).

The aspects identified (unconsciously) are (1) intensity, (2) substance, and (3) force or power. Here is an example. We speak of quantities of electricity, electricity can be strong (intense) or weak, and there obviously is a force (power) of electricity. Clearly, the same structure emerges in other classes of phenomena as well. Wiser and Carey (1983) have identified exactly this type of image in the reasoning of the Experimenters of the Accademia del Cimento (1667) applied to thermal phenomena. Carnot's analogy of water and heat is a result of reasoning based on the same gestalt—in explicitly differentiated form of a modern scientific theory (Carnot, 1824; Fuchs, 1996). And if we analyze our language concerning general abstract concepts such as love or pain, the same general gestalt having the same aspects can be discerned.

Metaphors for the Aspects of the Gestalt of Physical Processes

The aspects of the gestalt of a physical process are structured metaphorically. In fact, the third aspect is so rich that it constitutes its own gestalt with its own set of metaphors. The conceptual structures of these aspects are

- 1. Intensity is structured in terms of the metaphoric projection of the up/down image schema (schema of verticality) onto the concept in question. (See Johnson, 1987, on image schemata.) Examples: High speed, temperature rises, low pressure, higher voltage...
- 2. The amount of something is metaphorized as a fluid substance, where fluid substance is again an image schema. Examples: Electricity flows, momentum is transferred, heat has been stored, substance is produced, more liquid...
- 3. Force or power is related to the gestalt of direct manipulation. In other words, this concept has to do with how humans perceive and conceptualize causality. The gestalt of direct manipulation has been described by Lakoff and Johnson (1980, p. 70):
 - There is an agent that does something.
 - There is a patient that undergoes a change to a new state.
 - Properties 1 and 2 constitute a single event; they overlap in time and space; the agent comes in contact with the patient.
 - Part of what the agent does (either the motion or the exercise of will) precedes the change in the patient.
 - The agent is the energy source; the patient is the energy goal; there is a transfer of energy from the agent to patient.

The meaning of the first two is clear to physicists. The first leads to the concept of potential (intensive physical quantities) whereas the second serves to conceptualize extensive (additive) quantities as substance-like. The form of the third aspect of the gestalt of a typical physical process—that of force or power—suggests that it could be the source of our concept of energy. The relation between extensive and intensive quantities and energy is well-known from continuum physics (Eringen, 1971-1976; Müller, 1985) and from Gibbs' thermodynamics (Falk and Ruppel, 1979; Callen, 1985). Carnot (1824) expressed this relation succinctly for the first time in dynamical form. There is a visual metaphor that expresses

what he meant, the metaphor of the waterfall. In his book, The Motive Power of Heat, he wrote:

> According to established principles at the present time, we can compare with sufficient accuracy the motive power of heat to that of a fall of water The motive power of a fall of water depends on its height and on the quantity of the liquid; the motive power of heat depends also on the quantity of caloric used, and on what may be termed, on what in fact we will call, the height of its fall, that is to say, the difference of temperature of the bodies between which the exchange of caloric is made. In the fall of water the motive power is exactly proportional to the difference of level between the higher and lower reservoirs. In the fall of caloric the motive power undoubtedly increases with the difference of temperature between the warm and the cold bodies; but we do not know whether it is proportional to this difference.

It seems to me that the differentiation of the three aspects of the gestalt reached a first level of maturity in Carnot's work. This, and the strong use of analogical reasoning, led to a form of a thermodynamic theory which still serves as a model for how we can most easily understand the concepts of continuum physics, and as a consequence, of the physics as it transpires through the use of system dynamics modeling presented here.

Visual, Verbal, and Mathematical Expressions of Metaphors

If metaphors are structures of thought, they can be expressed in different ways: Through mimesis (Donald, 1991), visually (Arnheim, 1969), linguistically, mathematically... I will briefly discuss visual metaphoric expressions. Linguistic ones have been described above. At this point I cannot yet specify possible mathematical expressions of the metaphors identified here. The challenge of how to see images in equations might prove quite interesting for physics didactics. Mathematics is metaphor based, that much is clear (Lakoff and Nunez, 2001), but how this translates to our challenge I do not yet know.

A set of diagrams has been developed to express the elements of the gestalts discussed above, and the relations between these elements (see Fuchs, 1996, 1997a). The diagrams make use, among others, of the waterfall image created by Carnot. For our present purpose, however, the metaphors contained in typical system dynamics tools are of more immediate interest.

The examples presented before in Section 2 show that three types of reasoning are supported by visual expressions of underlying metaphors.

They are

- Substance-based thinking: Made evident by stocks and flows.
- Causal thinking: Visualized with the help of combinations of stocks and flows (single stocks, and interactions between stocks).
- Feedback thought: Expressed with the help of the thin connecting lines leading (more or less directly) from stocks to flows.

This corresponds to some extent to the structure of the gestalt and its aspects discussed above. The image schema of verticality and the gestalt of the waterfall (as a symbol of the power of a process) are not as visible as we might wish from the viewpoint of physics.

It appears to me that we should not underestimate the intelligence expressed by the creation of maps by hand or at the computer screen. The graphical user interfaces of system dynamics programs are more than mere gimmicks.

Roots of Analogies

I shall present a particular view of the origin and nature of analogies as they are constructed in continuum physics. In this view, a clear difference between metaphor and analogy emerges.

In general, metaphors are projections of a source domain onto a target domain (Fig.11). The metaphor Organizations are Plants projects our understanding of plants onto that of organizations. According to the nature of the source and target domains, one speaks of different types of metaphors. For our purpose, the simplest type of metaphor is of interest: The projection of an image schema onto a target domain. Image schemata are recurring structures of or within our cognitive processes which establish patterns of understanding and reasoning. They emerge from our bodily interactions, linguistic experience and historical context. They are some—if not the—most basic structures of human understanding (Johnson, 1997, Chapter 5).



Fig. 11: A metaphor is a one-sided projection of a source domain onto a target domain. A particularly primary form of metaphor results from the projection of image schemata.

It has been pointed out above that the first two aspects of the gestalt of physical processes (intensity and amount or substance) are structured metaphorically on the basis of the image schemata of verticality (for intensity) and fluid substance (for amounts or substance). In other words, we have, at minimum, two basic metaphors for a field of experience. If different phenomena in the physical world are abstracted as the same type of gestalt having essentially the same aspects, the same image schemata are projected onto all of the classes of phenomena—fluids, electricity, heat, substances, and motion—alike (Fig.12). Take heat and electricity and fluid substance. In physics we create the concepts of temperature and entropy, and of electric potential and electric charge, respectively, as measures of the aspects of intensity and of amount of heat or electricity.

As a result of identical metaphoric structuring, thermal and electric phenomena obtain a degree of similarity. They can now be compared and lend themselves to an analogy, a mapping of structure from one to the other, and back. Metaphors are two-sided projections of structure from one (previously) structured domain onto another (Fig.12).



Fig. 12: Analogies are made possible based on similarity of two structured domains. The similarity is the result of equal metaphoric structuring of each of the domains. The mapping is (more or less) symmetrical.

Naturally, the structuring of the domains of fluids, electricity, heat, substances, and motion also includes the aspect of force or power. Here, an entire structured domain—the gestalt of direct manipulation—is projected onto a sum-total of experience (such as heat or electricity). In physics, the structure of this gestalt is rather simple: Carnot's waterfall image basically says it all. The power of a process depends upon the

quantity of the fluid substance flowing through a level difference. It is proportional to both, .i.e., double the current of the fluid substance or double the potential difference leads to double the power. Again, the domains of fluids, heat, etc., are analogous in this respect. Most important for the further development of a subject is the following observation. Metaphors—the metaphoric projection of knowledge from one domain onto another—leads to entailments. We can reason about the target domain based upon the properties of the source. Take the example of the fluid substance. The fact that (real) fluid substances obey a law of balance can be directly transferred to the substance-like quantities of physics.

Continuum Physics and System Dynamics modeling

It is quite clear from the foregoing that continuum physics has the conceptual metaphoric structure outlined in this Section. As a consequence, system dynamics modeling of physical processes does as well since it models the spatially uniform subset of continuum processes. SD modeling obviously makes use of a successful form or human reasoning.

5 Summary

In summary, let me list some aspects of system dynamics modeling that might be important for the learning of a science such as physics. The first observation is that SD modeling is simple. The tools are learned easily. More importantly, by simple graphical procedures, we create formal structures that are commonly thought to be quite advanced, i.e., systems of initial value problems.

Second, system dynamics modeling is interdisciplinary. In physics, it allows us to treat fields such as fluids, electricity, heat, chemical processes, and motion in a strongly analogous fashion. We know why the methodology is so successful: It makes use of a fundamental form of human reasoning as evidenced by its metaphoric structure.

Third, modeling of dynamical processes using these modern tools is practical and powerful. It lets us integrate experimental and modeling activities quite easily. It supports the scientific method and serves as an integral tool in design procedures.

Finally, it supports the creative mind since it is "natural" in an important way. SD modeling reflects (at least some) fundamental aspects of figurative human thought. It is close to a full representation of the gestalt and its aspects which humans see in natural processes. The metaphoric projection of the same image schemata onto diverse phenomena makes these phenomena similar. As a result, fluids, electricity, heat, substances, and motion lend themselves to the application of analogical reasoning. Finally, let me add that some high school physics courses do make extensive use of the structures discussed in this paper. The first is the extensively applied and researched Karlsruher Physikkurs (Herrmann, 1989-1999), the second is a course introduced in Switzerland that makes explicit use of system dynamics modeling (Borer et al., 2005).

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An Instruction Model for Modeling with simulations: How to help student build their own model with simulations

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Introduction

Researchers have defined simulation, a concept related to microworld, as a model or simplified example of complex natural phenomena (Jonassen, 1996). Computer-based simulations in an instructional context mean using the computer to build models, or to model real-world phenomena in order to help students gain insights into the behavior of complex systems. Interacting with an instructional simulation can enable learners to gain a better understanding of a real system, process or phenomenon through exploring, testing hypotheses, and discovering explanations for the mechanisms and processes (Burton et al., 1984; Goldenberg, 1982; Lunetta & Hofstein, 1991; Mellar & Bliss, 1993; Raghavan & Glaser, 1995). This interactivity may provide opportunities for students to modify their mental models, by comparing the outputs of the model with their expectations (Jackson et al., 1996), and to engage or motivate students to explore and couple actions with effects which will lead to understanding.

Simulations not only allow learners to construct and manipulate screen "objects" for exploring underlying concepts, they also provide learners with the observation and manipulation tools necessary for exploring and testing hypotheses in the simulated world (Johnassen, 1996). However, there is not universal evidence of the effectiveness and efficiency of computer simulations. Some studies have shown positive effects (Brant, Hooper & Sugrue, 1991; Choi & Gennaro, 1987; Faryniarz & Lockwood, 1992; Grimes & Wiley, 1990; Mills, Amend & Sebert, 1985), but others have failed to find any advantages (Carlsen & Andre, 1992; de Jong, de Hoog & de Vries, 1992; Rivers & Vockell, 1987). Causes for discrepancies in these research findings are numerous but three major areas stand out: inadequate pedagogical support, shortcomings in the simulation design, and inadequate learning skills. For example, de Jong et al. (1994) suggested that simulation ineffectiveness is due to learner's inability to overcome the difficulties of interacting with a simulation on their own. Pedagogical support, such as reinforcing productive conjectures, discussing successful learning strategies, and relating phenomena to the discipline, could be missing. Learner difficulties could be due to concepts embedded in the simulation that are too abstract or a design of the simulation that is not meaningful to

learners. Learners may not know how to use problem-solving strategies such as the generation and testing of hypotheses, model-based reasoning and meta-cognition.

The role of computer-based modeling and simulations becomes more important in the learning and teaching of science due to the explosion in science information and in its accessibility through the World Wide Web. Computer simulation can help students to understand invisible conceptual worlds of science through animation, which can lead to more abstract understanding of scientific concepts. Quantitative data can be manipulated and visualized to form qualitative mental pictures or descriptions. Such complex experience can help students to identify patterns within simulations, formulate explanations for phenomena in terms of models and theories. Increasing computational speed and multimedia capabilities lead to development of more powerful modeling and simulation tools. We have developed hundreds of physics related java simulations on our server (http://www.phy.ntnu.edu.tw/ntnujava/). Our java simulations are very popular around the world. However, we found out simulation or modeling software alone will not make the above claims come true in the real classroom. Teachers need pedagogical support in order to make the above dream realized.

Modeling is to use a "conceptual world" to "model" a "real world". How to help student build their own physics model? How to implement simulation or modeling tools into the classroom in order to create an effective learning outcome? We all agree that modeling is not easy. Because we would like to build models that not only describe the behavior or results observed, but also explain why that behavior and results occurred as they did. And a good model also allows us to predict future behaviors or results that are yet unseen or undiscovered. Many questions need to be answered: how to generate representation or models, how to validate or test them, how to apply them to other situations, and what are their limitations. We present a theory-based Technology-Enhanced Learning (TEL) model that takes a situational cognitive approach, integrates the use of multimedia/modeling tools into instruction, and supports the development of students' conceptual understanding. Although this model was developed for instructional purposes, by focusing on students' cognitive processes it also becomes a learning model.

TEL Model: An Instruction Model for Modeling with simulations

Our model essentially integrates the work of Karplus and Thier (1967) on the Learning Cycle, and of White and Frederiksen (1998) on the Inquiry Cycle. The Learning Cycle was first proposed during the curriculum reforms of the late 1950s and early 1960s (Abraham, 1998; Karplus & Thier, 1967; Lawson, 1995; Renner & Stafford, 1972). It was developed as a way of translating the inquiry process used by scientists to advance students' active understanding. The Learning Cycle characterized scientific inquiry as consisting of three phases: exploration, invention, and discovery (Karplus & Thier, 1967). In the exploration phase, students gain hands-on laboratory or field experience during which they observe and make measurements in order to understand specific scientific concepts. In the invention phase, students discuss and explain their findings from the exploration phase. In the discovery phase, they apply the concepts they learned in the invention phase to verify the limitations of their understanding. White and Frederiksen (1998) proposed the Inquiry Cycle, which explicitly presents key components (question, prediction, experiment, model, and application) of scientific inquiry to students. In a process of scaffolded inquiry, students first formulate a question and then generate a set of competing predictions and hypotheses related to that question. They then plan and carry out experiments using both computer models and real-world materials; next, they analyze data and form a model to explain their findings. Finally, they apply their model to various situations in order to test the limitations of the model, and may generate a new question for the next inquiry cycle.

We propose the TEL model for designing learning activities in order to foster students' acquisition of synthetic knowledge through the integration of technology into their learning environment. The TEL model includes five cognitive phases, with a description of the mode of technology-implementation corresponding to each phase (see Figure1). The five phases are: (a) *contextualization*: students will confront an authentic and meaningful situation; (b) *sense-making*: students will visualize and represent the dynamic mechanics of the complex situation and simplify it; (c) *exploration*: students will plan and carry out their experiments or, given access to information on databases, explore scientific principles or relationships among variables; (d) *modeling*: students will form hypotheses or build models to explain their findings; (e) *application*: students will get the opportunity to apply concepts to different situations and identify the limitations of their models.

In following this cycle, teachers first provide an authentic situation to engage learners in the generation of a question or comprehension of scientific phenomena (contextualization and complexity); then, learners are better able to make sense of the underlying mechanics of the complex situation through scientific visualization. A set of exploratory learning activities (exploration) guides learners to test their hypotheses and formulate a model (decontextualization and simplification) to explain their observations and findings. Finally, they apply what they have learned to a variety of situations in order to reflect the limitations of their model, think how to improve their model and plan for the next exploration (reflection-exploration).



Figure 1: The Framework of the Technology-Enhanced Learning Model

The quality of computer technology's effects greatly depends on the setting in which the computer-related activity takes place, on the user's goal(s), and on his or her mindful engagement in the activity. To be effective, instructional methods and the media that deliver them must guide learners to effectively process and assimilate new knowledge and skills. Figure 1 shows one suggested way of applying the TEL model from the technology-implementation point of view: Situation Provider \rightarrow Animation Display \rightarrow Simulation Exploration \rightarrow Construction Pad \rightarrow Assessment Administration. The detailed descriptions of each TEL phase and the use of these components are as follows:

Contextualization

To motivate students and focus their attention on specific scientific phenomena, therefore, the first phase of the TEL model is contextualization. In this phase, teachers may use pictures or videos to evoke students' prior knowledge and experience of a given phenomenon. In this phase, students are encouraged to describe their observations about the phenomenon, gain an intuitive comprehension of it, and connect it to their personal experiences. The computer or other medium will provide a real-life situation in the **contextualization phase** which motivates students. Students can achieve cognitive comprehension by watching videos or pictures to evoke their prior knowledge and experience of a given phenomenon. Most often real-life situations are too complex for novice students to be able to extract key elements from the picture or video. Group discussion or scaffolding is required to help students know: what the problem is, why it is important, what key factors/concepts related to their tasks are, and how they can solve their problem. Videos or pictures used in the contextualization phase should emphasize the need to engage students in meaningful and purposeful activities, to help students see science as important, vital, and integral to their everyday lives, and to have them pay attention to "science in action" in their own life. Static pictures are useful for comparison or detailed analysis, while video is better if we want a dynamic learning process. An animation starting from real life phenomena, with the unnecessary parts faded out and the image reduced to key elements, can be very helpful to beginners. It is important to facilitate social interaction between and among students after either a film or static pictures are shown.

Sense making

Although pictures and videos are powerful tools for contextualizing learning in a meaningful situation, they usually contain irrelevant information that could distract students' attention from the scientific content embedded in a given phenomenon. Therefore, the second phase of the model supports students' ability to make sense of their observations and intuitive comprehension, and to use various representations to guide the direction of their thinking (Bell, 1997; Quintana et al., 2002). Research on educational technology has suggested several design features to help students make connections between their intuitive comprehension and scientific representations (Edelson et al., 1999; Quintana et al., 2002; White, 1993; Wu et al., 2001). These features include providing representations that reveal underlying scientific concepts (White, 1993), giving students the ability to manipulate and link multiple representations (Wu et al., 2001), and providing representations and language that build on students' intuition in describing complex concepts (Bell, 1997). Scientific phenomena often involve dynamic processes in time or variations in space. Computer-generated animations representing a dynamic natural phenomenon can be used to help students conceptualize the underlying scientific process, conjecture the rules or theorems that lie behind the phenomenon and even build their own models or theories to explain the scientific process. Animation provides a qualitative or visual representation of scientific processes. By representing the phenomena in an animation, we allow students to induce the possible causes of recurring phenomena in the **sense-making phase**; this is the capacity for induction. A well-designed animation containing these features could help students make sense of what they observe from pictures or videos, and guide them in visualizing the scientific concepts embedded in a particular phenomenon.

Exploration

During the sense-making phase, students develop an initial understanding of a phenomenon and generate simple rules or hypotheses to explain what they have observed. To develop a deeper understanding of scientific concepts, they have to explore the concepts and test their explanations (Roth, 1997). In the third phase of the model, therefore, students are provided with more opportunities to form and test their hypotheses. Simulations can offer such opportunities. Features such as allowing students to manipulate the quantities of variables and observe changes (de Jong & van Joolingen, 1998), linking conceptual information (e.g. equations) to representations (e.g. graphs) (Kozma et al., 1996), and providing situations in which students can test their ideas could encourage students to explore concepts. By exploring the simulation students form hypotheses, test them and develop a scientific model in the exploration phase. This is an essential feature of scientific inquiry. Interacting with simulations, students can also construct relationships between variables, which in turn will help them move to the next phase, that of constructing a scientific model. Quantitative relations between key factors/variables can be simulated with computational tools. Exploration of the simulation helps students to discover the relationships among variables.

Modeling

A model can focus students' attention on the components of a phenomenon or a system (i.e. objects, variables, factors or relationships) and help them elaborate on interactions within the phenomenon (Gobert & Buckley, 2000; Ingham & Gilbert, 1991). Constructing a model can thus engage students in such learning activities as identifying variables. making connections among variables, and verifying the accuracy of the model (Fretz et al., 2002). In the modeling phase, then, students are encouraged to synthesize the context or network of the phenomenon's interrelationships and its possible explanations, and so develop a coherent understanding of the phenomenon they are investigating. The construction pad are learning/modeling tools that can assist students' modeling skill through symbolic representation. Furthermore, with tools like "easy java simulation" (Hwang & Francisco, 2003), they can form hypotheses, modify the relations between variables, compare the generated simulations and the real phenomena, test their own hypotheses and establish possible scientific models. They then may display their constructed scientific model in the modeling phase; this is schemabuilding. Learning tools used in this phase should provide students with a working space in which to develop, modify and connect ideas, reflect on their modeling process, and evaluate the accuracy of their model.

Application

Learning cannot be separated from the "act of knowing," for "what is learned' is an integral part of "how it is learned and used." It is important to provide opportunities for students to apply their new concepts in related situations and allow them to verify or identify limitations in the scientific model they have created. Finally, in the **application phase** students should go through an evaluation process in order to know their learning efficiency and the applicability of their own generated model; this is reflection. One way to verify the accuracy of the students' model is to apply it to different situations. In doing so, students should realize the errors and limitations of their model, transfer ideas from one setting to another, reinforce their ideas, and thus gain a new understanding of the phenomenon and relevant concepts. This application phase could also help students to overcome the "inert knowledge" problem by fostering the conceptual understanding that will come when the situation is relevant to what they have learned (Krajcik et al., 1999). To promote the application of knowledge, the designers of learning tools should consider including a database using similar situations, and provide scaffolds to support students in making comparisons among situations and in examining the applicability of their models.

"Research shows that it is not simply general abilities, such as memory or intelligence, nor the use of general strategies that differentiates experts from novices. Instead, experts have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment" (Bransford, Brown, & Cocking, 2002, p.31). The main purpose of the Situation Provider and Animation Display is to develop students' ability to notice the most important features or aspects of their problem. The Simulation Explorer and Construction Pad are designed to help students organize, represent, form hypotheses and interpret information based on the simulation. Here the learning process is just as important as the learning context.

One does not interact with the computer but with the specific software program run on it. The question is whether "the program" can provide (or can be designed to provide) the specific activities, goals, and conditions for cognitive involvement which are requisite. Both the content and the instructional methods that help people know this content should be considered when selecting appropriate software tools for science learning. The final goal of the TEL environment is to help students construct their own understanding instead of merely being passive receptors of instructional content. However, the short term goal during each phase of the TEL model could vary from information acquisition (receptive) to response strengthening (directive) to knowledge construction (heuristic).

Conclusion

Usually, the learner regards the computer simulation as a black-box. After the learner performs an input-output analysis, he or she can state the functional dependency relations between input and output (Goodyear, 1992). The strength of a simulation is to force students to retrieve or discover relevant knowledge, experiences and problem-solving skills in authentic situations. Exploratory simulations require students to take more responsibility in learning processes (de Jong & Njoo, 1992; Thomas & Hooper, 1991). With the help of scaffolded support from instruction, students can generate mental models based upon their interactive experiences with simulations (Suits & Diack, 2002).

Taiwanese students are near the top when the math and science scores of student in industrialized nations are reported in TIMSS 2003 study. However, most of the students did not like physics at all. There are just working very hard under the pressure from their parents. Many young kids in the elementary school like science. However, most of them did not like science or physics during their high school years. We have created hundreds of physics related java simulations and posted them on the NTNUJAVA web site (http://www.phy.ntnu.edu.tw/ntnujava/) to help students gain deeper understanding of physics concepts. And we hope they can enjoy the fun of physics as we do. We did find students who can use computer simulations to visualize the mechanism behind complex systems, and to see into phenomena that are not accessible to direct observation, therefore enhancing their comprehension of the underlying physics concept. However, we also found students who only gain the visualization effect from the simulation. They did not really understand the physics principles which govern the simulated processes. So we developed the above model to help teachers to implement simulation/modeling tools into their classroom to help their student. The study of the model is underway. We will report our research findings based on this model in the near future.

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Symposia

Modeling Assessments of Innovative Physics Courses

Symposium Overview

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Response by: Frits Gravenberch, Acting President, Netherlands Association for Education in Natural Sciences (NVON), The Netherlands

An innovative calculus-based university physics course was evaluated using a mixed methods action research(MMAR) model. A brief discussion of the characteristics of the experimental physics course and control course are given. The main focus of the symposium will be on the attributes of the MMAR model. The model includes qualitative and quantitative aspects. An overview of the MMAR model is presented and the interview protocols used in the pre, mid-term, and post interviews of students and instructors of the experimental course are discussed. The written questionnaires used to assess students' and instructors' pre-post attitudes toward science (physics) and technology, their preferred approach/model for teaching/learning physics, and their particular orientation to the nature of science are presented. An explanation of how the personal interviews and quantitative questionnaires enhance the research design will be given.

In response, Mr. F. Gravenberch, NVON Acting President, The Netherlands, compares the MMAR evaluation to results of 'similar' projects that were conducted in the Netherlands and comments on teachers' expectations of outcomes of projects in curriculum development.

The presentations are available on the website: http://www.hope.edu/GIREP2006.

INTRODUCTION

Two experimental sections of university calculus-based general physics sections were offered using The Physics InfoMall CD-ROM, Excel, word-processing, and electronic communication technology to see if technology could be used to enhance the learning of physics. It was anticipated that the experimental physics sections would help faculty and students focus on addressing ill-defined problems from the natural world.

Calculus-based Physics(CBP) Program

The department expectation was that the experimental sections would follow the same course content and goals as the regular general physics classes, and take the same final exam. The regular physics course is a rigorously controlled, competently organized and presented program designed to achieve a high level of mastery in reproducible physics knowledge (i.e., facts, laws, theory), and the utilization of this knowledge in the solution of standard undergraduate physics problems and applications. These regular students are expected to know and reproduce stereotypic "theoretical" and "conformational" physics approaches supported by a traditional text where the outcome of such instruction could be expected to have not much more than a routine application within a clearly identified occupational context.

Student Population

During the semester of the study, approximately 540 students took firstyear physics. These freshman students were regarded by faculty as being "highly motivated" and having "strong math skills." Two sections of 24 students each were created on the basis of positive responses to an E-mail request for volunteers. A deliberate attempt was made to include women and minority groups in the experimental sections. "Control" sections were selected for comparison with the "experimental" sections by matching instructors in the regular sections with those in the experimental sections as well as possible. Five sections were chosen as control groups.

Electronic Resources

Students in the two experimental sections worked in groups of two through four using physics laboratory PCs running under Windows fitted with a CD-ROM drive. The hardware was up-to-date and the software was the most modern available. While students in all sections had access to the campus E-mail facility, the experimental sections began with a special electronic conferencing capability. Use of the electronic communication tools, Excel spreadsheet software, and the Word pad available in the InfoMall CD-ROM had a deliberate emphasis in teaching and learning.

While the experimental physics syllabus content objectives were the same as the control sections, the experimental activities were constructed so that students had opportunities to make maximum use of the CD-ROM's research potential and its capacity to aid unique, diverse, and generalizable approaches to problem solving. It was anticipated that concept learning and depth of understanding could be facilitated through

the wide range of materials that students could have addressed to meet their personal learning needs.

In addition, these computer-based learning activities were intended to encourage more autonomy and cooperative effort in learners. In so doing, the instructors set up a situation of potential conflict with students' past experiences and associated attitudes and values around the teaching and learning of physics.

Research Design

Since an important component of the experimental project was to be the development of model instructional strategies and activities for the use of the CD-ROM, it was agreed that a mixed methods action research model would be used to evaluate the experimental program. Pre/post tests were used to measure aspects of growth; summative tests and exams were used to measure mastery of syllabus content and applications. Pre- and posttests included Nature of Science Profile (NOSP) (Nott & Wellington, 1993), Strategies in Teaching Physics (SITP) (Dettrick, 1995), Attitude to Science/Physics (ATP) (Dettrick, 1988), and the Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992).

Student interviews and reflective student diaries paid particular attention to the functionality of teaching and learning with the CD-ROM. They provided a database which was used periodically to inform instructional staff about strengths and weaknesses of the CD-ROM as an instructional tool and the most effective means for its utilization in teaching physics. Staff notes of the process of progressive change throughout the semester were used to inform and document the action research.

Initial analysis of the data permitted observations about 1) diversity of beliefs and attitudes in both students and instructors, 2) changes in perception about the nature of science and about preferred teaching/learning strategies, 3) changes in attitude toward physics learning, 4) the advantages and disadvantages of the use of the CD-ROM as perceived by instructional staff and students, 5) descriptions of special skills developed in electronic information retrieval and application in problem solving, and 6) the use of electronic tools for individual and group work. Researchers also reflected on the institution's desired educational outcomes in relationship to the initial vision and culminating experiences in the experimental sections.

CURRICULUM CHANGE

Approach to Teaching

Lecture time which typically is devoted to the delivery of subject content was deliberately set aside in favor of activities that were designed to facilitate the development of broader professional skills grounded in critical thinking and problem solving. The major changes that the project instructors designed and implemented included:

- requiring inventive problem solving with respect to complex situations which had ill-defined approaches and unclear solutions
- ✓ deluging students with relevant and irrelevant information which required analysis, criticism, and synthesis.
- ✓ modeling conditions met by human beings in the real world rather than work within an abstracted or generalized framework modified to ease instruction and simplify learning.
- ✓ encouraging scholarly research using the CD-ROM resources.
- ✓ planning for individualized problem solving.
- \checkmark requiring learner creation of problems to be solved by peers.

Students' Perceptions of the Experimental Process

Over the semester students in the experimental sections reported experiences and attitudes which represented several recurring themes:

- ✓ negative impact of time constraints
- \checkmark confusion in choice-making activities
- \checkmark problems working with others toward a common goal
- ✓ concern about preparation for assessment
- ✓ technology as a tool for studying physics added unwanted complexity

Attitudes among Instructors

The teaching/learning curriculum in CBP at this institution is structured in such a way that it appears that instructors teach homogeneously and students learn homogeneously against a homogeneous experience base. Nothing could be further from the truth. The instructional staff involved in this project represent a diversity in professional experience, preparation, personal philosophies and personality profiles.

The "Attitude to Physics" profile showed that the experimental class instructors were not significantly different from the control groups' instructors in their attitudes.

The desired institutional outcomes include phrases like *exploring contradictions between personal assumptions and evidence, framing ill- defined problems*, and *intellectual curiosity*. Such outcomes appear to go hand-in-hand with an approach to instruction which requires the student to be personally involved in investigations or inquiries and consideration of the outcomes of those investigations. Subtest scores indicate that some instructors' attitudes were weakly disposed towards personal inquiry in physics. "Adoption of Scientific Attitude" and "Disposition to Practical, Hands-on Involvement" were the two sub-tests where the strongest differences between instructors occurred. The Attitude to E-technology

demonstrated the greatest range of diversity among the instructors. Some of the instructor responses indicate slightly negative responses. What the instructors felt and saw themselves doing normally in physics teaching was not aligned with the aspirations they had for the attitudes and actions of the students they taught with respect to electronic communication technology.

Attitude toward Physics among Students

In examining the data from the Attitude to Physics survey instrument, the researchers began to elicit a picture of the students' adopted and often unexamined attitudes in three dimensions: 1) toward scientific inquiry in physics, 2) toward teaching/learning physics, 3) toward physics as a practical, hands-on activity. The way in which the ATP survey is constructed, a positive response to questions addressing teaching and learning issues in physics would indicate positive support for inquiry rather than a content, cultural-reproductive approach to physics. A content--or reproductive--approach to physics does not facilitate inquiry or critical thinking which is the real-life approach to problem solving, rather than the popularly-assumed computational problem-solving approach.

Considering the mean as a measure of central tendency, at the beginning of the semester the tendency of all seven project classes was toward vague to moderate support for an inquiry or activity-based approach to physics. The students may have adopted this position as a result of their previous high school experiences. In the scores from the post-tests, student support for a practical, inquiry, activity-based, hands-on program declined. The data collected from diaries and interviews support the observation that participative, inquiry-based physics programs increase the stress because of the demands associated with allocation of precious time.

As a result of the data analysis, researchers recommended that when instructors plan and innovate curriculum change in physics courses, they may wish to consider time constraint stresses that force students to make decisions that devalue academic enterprises. The effect of this constraint appears to reinforce traditional content-based, reproductive and rhetorical approaches to teaching physics. This is a contradiction to modern approaches to teaching science and to theories of cognitive development. Furthermore it mitigates against a research-based culture which one would expect in college physics programs.

On another dimension, researchers encouraged instructors to re-examine their views of RIGOR as not only associated with level of difficulty or the "covering" of masses of memorizable content to which students may be exposed. A recent definition (Strong, 2001) invites instructors to consider rigor as a curriculum goal: *Rigor is the goal of helping students develop the capacity to understand content that is complex, ambiguous, provocative, and personally or emotionally challenging.* Inquiry-based programs like the experimental sections make strong cognitive demands on students and force them into more exacting, subtle real-world decisions. The ability to manage difficult content should be a fundamental skill all students need both in school and out. It must be realized that both inquiry and rigor require time and flexibility that conflict strongly with the notion of "covering" a large quantity of syllabus material. Inquiry approaches to physics incorporate model building and revision based on feedback and the tentativeness of solutions. As in physics itself, there will always be the possibility for a more refined response.

If students are left to their own devices, cognitive, attitudinal, and behavioral change may occur gradually, in an evolutionary fashion--but this cannot be guaranteed. It is critical that the higher education experience offer multiple opportunities, beginning in the first year, to grow into and evolve an ever expanding and more sophisticated world view. This does not develop magically, or spontaneously at the moment of graduation. Learners must be given increasingly demanding academic situations in which to gain confidence and competence in examining individual situations, weighing the circumstances, supporting a position, and making decisions.

The Challenges of Innovation

There are few rewards or incentives for teaching which develops critical thinkers and problem solvers. Faculty are diverse individuals and must be given the richness of time and opportunity to discuss important issues with one another and come to consensus on a few critical dimensions:

- 1. articulate definitions of critical thinking and problem solving that will best serve the students and transfer to their professional lives.
- 2. determine how is it possible to assess critical thinking and problem solving and give students appropriate feedback so that they may grow in their depth and breadth of knowledge, in their skills, and in their positive attitudes and disposition toward physics.
- 3. determine what will be the overt rewards for doing critical thinking and for teaching critical thinking.
- 4. introduce progressive changes to the nature of the measurement of "success".

Deans and department chairs make a critical error if they assume that there is a single profile of the "best" physics teacher. As has always been the case, faculty will be diverse individuals. Entry-level training for new instructors will be critical in developing a strong teaching staff with a common commitment to the department goal. It is important to encourage a department or institutional norm which encourages collaboration, team problem-solving, and information and skills sharing on the use of ever-evolving technology that could be appropriate for the classroom setting.

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Response to 'Modeling Assessments of Innovative Physics Courses'

Frits L Gravenberch

Summary

Fuller c.s. present in there their paper: "Modeling Assessments of Innovative Physics Courses" results that relate to teachers and students in Tertiary Education.

Naturally, differences exist with teaching conditions in Secondary Education⁵. This contribution first illustrates that nonetheless many of the results reported in the paper are quite analogical to the ones we came across working with teachers and students in Secondary Education, in the Netherlands. Finally, two reasons for explanation of the resemblance are discussed.

Comments to "'Modeling Assessments of Innovative Physics Courses'"

In the section in the paper of Fuller c.s. :'Introduction' it is stated that '*It* was anticipated that the experimental physics sections would help faculty and students focus on addressing ill-defined problems from the natural world.'

Former Dutch innovation projects had similar curricular aims. During e.g. the so called 'PLON' project (1970-1983) teaching materials were developed and field tested on the basis of the idea that particular 'realistic themes' such as "Bridges" and "Traffic and Safety" would be appropriate vehicles to improve students' motivation to master content elements from the physics school curriculum. In short, evaluation (Wiersma ...) at that time illustrated that teaching with PLON materials indeed enhanced students' interest in the new kind of teaching contexts and classroom activities. Efforts to establish – compared to 'common physics education at the time'-a considerable improvement in students' concept development, however, were not too successful (CITO ..).

In the section: 'Electronic Resources' it is stated that: 'While the experimental physics syllabus content objectives were the same as the control sections, the experimental activities were constructed so that students had opportunities to make maximum use of the CD-ROM's

⁵ Main differences between science students and teachers in Tertiary and in Secondary are probably:

[•] Students in Secondary are, generally speaking, far more involved in initial stages of development of science-related attitudes, concepts and skills compared to Science students in Tertiary

[•] Teachers in Tertiary relate far more as academic experts to their students compared to teachers in Secondary who deal with youngsters to whom science related subjects are (only) a (very) limited part of their school curriculum as a whole.

research potential and its capacity to aid unique, diverse, and generalizable approaches to problem solving.'

In 'Curriculum Change' it is stated that: 'Lecture time which typically is devoted to the delivery of subject content was deliberately set aside in favor of activities that were designed to facilitate the development of broader professional skills grounded in critical thinking and problem solving.

Experiences from Dutch efforts to innovate the science curriculum, indicate that our expectations to develop 'meta-skills' such as *generalizable approaches to problem solving* and *critical thinking* in classroom teaching, in addition to content elements included in the traditional curriculum are not necessarily non-realistic but mostly very difficult to realize. E.G. efforts to adapt along similar lines the national physics examination programs, by a national (governmental) curriculum committee (WEN, 1993), resulted unfortunately in a program which students and teachers felt very hard to realize in actual classroom practice. Comparable with the findings of Fuller c.s. these implementation problems were related to problems people had to cope with traditionally defined classroom constraints such as the total number of teaching hours that was available, the kind of didactical resources, the lack of available skills in teaching the new curriculum, and learning outcomes for students.

We find similar observations in this paper, where it is stated in 'Students' Perceptions of the Experimental Process that:

Over the semester students in the experimental sections reported experiences and attitudes which represented several recurring themes:

- ✓ negative impact of time constraints
- ✓ confusion in choice-making activities
- ✓ *problems* working with others toward a common goal

✓ concern about preparation for assessment

Over the last decades CBL developers - e.g. AMSTEL Institute - as well as more general educational researchers - e.g. at SLO, Utrecht University - in the Netherlands made many efforts to enrich the national science examination syllabi with ICT-related content elements. Currently, we have arrived at the stage of piloting so-called *computer examinations (COMPEX)* in which students' abilities in applying computer skills to lab work kind of situations, are examined during the so-called central <u>written</u> examinations.

• Many of the experiences reported in the paper of Fuller c.s. are comparable to the ones that were observed in the Dutch context, eg. Upper Secondary students' who where exposed to programs such as Word and Excel during 'Informatic classes' already in Lower Secondary nonetheless encountered serious problems when they had to apply particular 'basic computer skills' during the
COMPEX-exams. Earlier reports - Inspector's review - that also in Dutch schools,

- 'technology as a tool for studying physics added unwanted complexity'
- some student support for a practical, inquiry, activity-based, hands-on program declined

In conclusion

Apparently, quite a few observations of Dutch researchers with High School students are very comparable with the ones reported in the paper by Fuller, c.s.

In our experience this probably results from two basic problems with innovating curricula:

- short vs. long term aspects of innovative effects. Our experiences from many decades of curriculum and didactical research indicate that innovative and wanted effects of curriculum innovation are rather easily acknowledged and proofed by respectively well motivated teachers and researchers who were involved themselves in curriculum innovation projects (short term). Innovative and wanted effects of curriculum innovation in the long term are only noticeable with 'common' teachers and students who could benefit from a variety of supportive facilities over a rather long time.
- danger of internal blow up of the curriculum Most efforts in the Netherlands to try and innovate the school curriculum and common teaching practice unfortunately, start by issuing new national examination programs. So far, none of the national (governmental) committees in charge of developing these programs escaped from the pitfall to develop a new program by 'simply' adding new content elements to the already overloaded existing collection of concepts, laws and formulas.

However, the recently installed committees⁶ unanimously decided to try and avoid these pitfalls by a. not founding their program proposals on the traditional inventory of academic content elements but on a new curricular structure i.e. a small number of *'basic concepts'* together with carefully selected *contexts* (Boersma). And, to start their work by defining a well defined set of curriculum goals and objectives before selecting particular content elements during the process of putting together a proposal for new examination programs. And –last but not least- it has been decided that before issuing the new examination programs, their actual merits will be established by field testing teaching materials that are developed on basis of the new proposals by teams which contain both teachers and 'educationalists.'.

⁶ This recent development will be explained in more detail at the seminar.

Problems in the Teaching of Energy: Historical Burdens of Physics

Symposium Overview

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Abstract

If our symposium was in German, its title would be "Altlasten der Physik". This title meets the content of our contributions very accurately, but is almost untranslatable into any other language. In English it would translate, literally but colorlessly, as "Old Charges of Physics".

The term "Altlast" came into being in the early 1990s to describe a phenomenon that showed up after the breakdown of the communist regime in East Germany. The rotten and hazardous industrial plants and other infrastructure remnants that are not only useless, but also necessitate large investments for their rehabilitation, are called "Altlasten".

In physics there are such infrastructure remnants from the historical development of the subject. We hope that by identifying them, we can begin to make the investment towards fixing them. We have chosen the title "Historical Burdens of Physics": Like the hazardous sites of East Germany, these concepts once served a purpose, but now they must be cleaned up before further gains can be made.

More of them can be found on our web site

http://www.physikdidaktik.uni-karlsruhe.de

In German: click on "Kolumne: Altlasten der Physik"

In Spanish (in preparation): click on "Publicaciones en Español"

Forms of energy

Subject:

It is common knowledge that energy exists in various forms. Kinetic, potential, electric, chemical energy and heat are examples known to everybody; "converting energy from one form into another" is a common way of speaking.

Deficiencies:

Although we often speak about energy forms, we run into difficulties as soon as we try to define them. We are not consistent in the necessary distinction between the forms of stored and transmitted energy. On the contrary, in our casual formulations we tend not to differentiate the two concepts. While for heat and different types of work certain rules have been established, the classification of storage forms of energy seems vague and arbitrary, with the exception of some mechanical textbook examples. Which part of the energy of a steel spring or of an air molecule is mechanical, thermal, chemical, electric or magnetic? Which part is translational, rotational, oscillatory or electronic? Which part is kinetic or potential? Which part is ordered or unordered? The fact that we obtain reasonable results without knowing the answers to these questions leads to the conclusion that the classification is of no importance for our physical arguments.

Origin:

In order to account for the role of energy within the network of physical phenomena, enumerating energy forms is a means of expression which is difficult to avoid. This can be seen in a citation of F. Mohr (1837) from the time before the discovery of the conservation of energy: "In addition to the 54 known chemical elements there exists in nature yet another agent, the name of which is Force: Under appropriate circumstances, it appears as movement, chemical affinity, cohesion, electricity, light, heat and magnetism, and from each of these forms of appearance, all of the others can be brought into being."

Disposal:

We save many words if we refrain from useless differentiations. It is often comfortable to speak about bottle milk and carton milk. It is completely useless, however, to call the process of transferring or drinking it "milk conversion," or to define the content of a glass or of the stomach as different "forms of milk." The situation is the same when speaking about the energy. The clearest, but perhaps not the most comfortable solution is to refrain from speaking about energy forms completely. Of course, just as for a patient who after a long period of convalescence leaves his crutches for the first time, it takes time until one is acquainted to the newly acquired freedom and also to be able to cover difficult terrain.

Pure energy

Subject:

In textbooks and scientific reviews one often finds statements that say electromagnetic radiation is pure energy. Here is an example of such a formulation [1]: "When a positron encounters an electron, the two particles annihilate each other and produce pure energy in the form of gamma radiation." Or another example [2]: "A massive particle and its anti-particle can annihilate to form energy, and such a pair can be created out of energy." A similar point of view is expressed in the following formulation [3]: "... light can also be described in terms of photons, discretely emitted quanta of energy."

Deficiencies:

It is obvious that an electromagnetic wave is not pure energy. The electromagnetic field is a physical system, i.e. a thing, for which every standard physical quantity has a certain value, and not only the energy. So, in general for an electromagnetic field, apart from just the energy, the extensive quantities momentum, angular momentum and entropy also have non-zero values. But intensive quantities also have certain values, just as is the case for other systems. So the electromagnetic field has a pressure at every point. (The pressure depends on the direction and is therefore a tensor.) In certain states, i.e. in those states that are usually called thermal radiation, the field has a certain temperature and a certain chemical potential. Identifying the radiation with one single quantity is simply not correct. The radiation is a physical system, something that is given to us by nature. Physical quantities on the contrary are products of the human mind. They are tools for the description of systems. Correspondingly, a photon, the elementary portion of the system "electromagnetic field", is more than just a quantum of energy. The photon also carries other extensive quantities in addition to energy, such as momentum and angular momentum.

The confusion between the concepts "quantity" and "system" also manifests in a kind of formulation often encountered in which energy and matter are presented as two concepts on an equal footing [4]: "So if galaxies are all moving away from one another [...] it seems logical that they were once crowded together in some dense sea of matter and energy."

Origin:

There are probably two causes for the erroneous identification of the quantity "energy" and the system "electromagnetic field." Apparently, on the one hand the energy was seen as more than just a variable in a theory, and on the other hand, the field was not taken seriously as a system.

After the introduction of the energy in the middle of the 19th century, its comprehensive significance in science was quickly understood. However, the enthusiasm about the importance of the new quantity led to an overestimation and misinterpretation of it. Energy was conceived, in particular in the circle of the "energeticists", as a kind of substance. So, one can read in Ostwald's 1908 book *The Energy* [5]: "Therefore, the energy is contained in all real and concrete things as an essential component, which is never absent, and therefore we can say that the energy embodies the actual reality."

On the other hand, the electromagnetic radiation was not accepted as what we today understand by the concept. We now know that it is a system like other system, for instance an ideal gas, or the phonon system of a solid. Like other systems, the electromagnetic field consists of elementary portions. What the hydrogen molecules are to the hydrogen gas and the phonons are to the lattice system of a solid, the photons are to the electromagnetic field.

This misunderstanding of the physical quantity "energy", as well as of the physical system "electromagnetic field", has left its traces. Although we have known better for a long time, we still easily use sentences like those cited at the beginning.

Disposal:

Instead of saying that pure energy is created in a reaction of an electron and a positron, say that a photon results. And instead of saying electromagnetic radiation is pure energy, say that the radiation carries energy, but besides energy it also carries other extensive quantities such as momentum, angular momentum and entropy.

List of references

[1] Scientific American, December 1993, S. 44

- [2] Penrose, R.: The emperor's new mind, Oxford University Press, S. 308
- [3] Scientific American, April 1993, S. 2
- [4] Scientific American, October 1994 S. 32
- [5] Ostwald, W.: Die Energie. Verlag Johann Ambrosius Barth, Leipzig, 1908, S. 5.

The Energy Mass Equivalence

Subject:

Einstein's energy mass relation $E = mc^2$.

Deficiencies:

In many schoolbooks and magazines we find the statement that Einstein's energy mass relation means that mass and energy are different manifestations of the same physical quantity, and energy and mass can be transformed one into the other [1]. If this statement was true, we could

distinguish energy from mass. A decrease of energy would be associated with an increase of mass and vice versa. However, it is not true, and it is not what Einstein's relation tells us. According to this relation, mass and energy are the same physical quantity, measured with different units.

Origin:

Possibly the culprit is Einstein himself:

"It follows from the special theory of relativity that mass and energy are both but different manifestations of the same thing, a somewhat unfamiliar conception for the average mind. Furthermore, the equation ... in which energy is put equal to mass, multiplied for the square of the velocity of light, showed that a very small amount of mass may be converted into a very large amount of energy and vice versa. The mass and energy were in fact equivalent, according to the formula mentioned above."

Instead of saying "may be converted into" he should have said "corresponds to".

Disposal:

Teaching should make clear the following:

1. The quantity known before as energy also has the properties of the quantity known before as mass, namely weight and inertia. A charged battery is heavier than an empty one. Hot water is heavier than the same amount of cold water; a moving body is heavier than the same body at rest, and so on. The weight differences in these examples are so small, however, that it is impossible to measure them.

2. The quantity known before as mass has also the properties of the quantity known before as energy. At a first glance, this assertion seems unbelievable. A typical property of energy is that it allows us to do some useful work. So one might expect that with 1 g of sand one should be able to realize a work of $E = 1 \text{ g} \cdot c^2 \cong 10^{14} \text{ J}$, what is obviously not true. However, we can never take profit of all the energy contained in a system. With "compressed" air of 1 bar we cannot drive a jackhammer; with "warm" water of ambient temperature we cannot drive a thermal engine. With gasoline alone we cannot run a motor. We also need oxygen. So it should not be surprising that we cannot run or drive anything with 1 g of sand alone. We also need 1 g of anti-sand. But if we had the anti-sand, it would work.

List of references

[1] "...This pair annihilation is the conclusive proof of the famous Einstein's law $E = mc^2$ for the transformation of mass into energy."

Tendency to the energy minimum

Subject:

The common reason given as a cause of a process is that the system reaches a state of minimum energy as a result of this process:

- a pendulum comes to rest at its low point
- a floating board tilts on its side
- a soap bubble forms in a spherical shape
- a sponge sucks up water
- a quantity of electric charge distributes on a conductor
- excited gas atoms emit photons
- positive and negative ions arrange themselves in a crystal lattice
- heavy nuclei decay.

Deficiencies:

Without saying it explicitly, all of these statements assume that each system aims at a state of minimum energy and proceeds to this state, provided it is not hindered by some circumstance. Formulated this way, however, the statement doesn't make sense. If one system reaches a state of minimum energy, then the complementary system, the environment, must reach an energy maximum due to the conservation of energy. The same argument applied to the environment would yield the opposite result. Thus the above assumption cannot be valid generally. So for which system is it valid? The answer comes from thermodynamics. The system must, as W. Gibbs expressed it in 1873, be closed for everything except the energy necessary to keep the entropy constant. The entropy S_p produced by processes occurring within the system appears only in the environment, and with it the energy TS_p coming from the system, where T is the temperature of the environment. Since S_p and T are always positive, the system always loses energy, since any other energy exchange that could compensate the losses is forbidden. Seen in this way, the tendency to the minimum energy is nothing more than a consequence of the entropy principle, applied to a particular class of systems.

Origin:

In mechanics we ignore the thermal properties of things. Levers, pulleys, springs, blocks and ropes are considered objects that cannot be heated, i.e. whose temperature and entropy cannot change. In fact we are tacitly ascribing the entropy created by friction to the environment. Under these conditions, we are allowed to speak of the tendency to an energy minimum. The same applies to systems in many other parts of physics – hydraulics, electricity, atomic and solid state physics and so on. Because

we don't mention the production of entropy as the cause for these processes, we get the impression of an independent natural principle.

Disposal:

We can talk about entropy production in systems explicitly. Like so often, our strained relationship to entropy misleads us to questionable surrogates. The fundamental evil, which as a consequence has endless difficulties and opposes itself to any attempt to remedy, is the dogma of the heat as a special form of energy, which for one and a half centuries has been affectionately cared for, and which is anchored in the first law of thermodynamics. Only if we are ready for a revision can a lasting improvement be expected.

Isolated Systems

Subject:

In order to formulate the conservation of energy or of other physical quantities, we often refer to an isolated system. We imagine a region of space whose boundaries are impermeable for a current of the quantity under consideration. The quotations (1) and (2), which refer to the conservation of energy, are taken from books for the secondary high school and are highlighted in these books.

(1) "In a thermally and mechanically isolated system the total energy is constant."

(2) "In an isolated system the sum of all energies is always constant. The total energy is conserved.

 $E_{\text{total}} = E_1 + E_2 + \ldots + E_n = \Sigma E_i = \text{constant}$

 E_1, E_2, \ldots, E_n different energy forms"

Deficiencies:

The concept of conservation of an extensive or substance-like quantity is not a difficult concept. This has to do with the fact that we can easily represent these quantities pictorially: We imagine them as a kind of fluid or stuff. The conservation of a quantity *X* can then be stated in the following way: "*X* cannot be produced and cannot be destroyed."

Here the exact wording doesn't matter. Conservation is something that we can easily express with words of the common language.

A consequence of this statement is that the value of X in a region of space can change only if a current of X flows into or out of the region. Mathematically the statement can be expressed in the following way:

$$\frac{dX}{dt} + I_X = 0$$

Here dX/dt is the rate of change of X in the considered region and I_X is the flow of X through the boundary surface.

A formulation of the principle of energy conservation that refers to an isolated system is a special case of this statement. "The system is isolated" means that there is no flow through the boundary surface. However, the isolation is an unnecessary restriction because the considered quantities are conserved independent of whether the system is closed or not.

To convince myself that the number of my students "is conserved", there is no need to close the door of the classroom. There is no problem if, from time to time, somebody comes in or goes out, as long as I ascertain that the number of students in the classroom increases by one when someone comes in, and decreases by one when someone goes out.

Origin:

The fact that we formulate conservation with reference to an isolated system is a leftover of the troublesome development of the concept of energy as a substance-like quantity. Until shortly before the beginning of the 20th century, the localizability of energy was not acknowledged. It was not yet possible to associate a density, a current and a current density with it. In 1887 Max Planck [1] wrote in a historical survey about the energy:

"... according to this definition the amount of the energy is measured only by these external effects, and if one wants to attribute any imaginary material substrate to the energy, then one has to look for it in the environment of the system; only here the energy finds its explanation and therefore also its conceptual existence. As long as one abstracts completely from the external effect of a material system, one cannot speak about its energy, since it then is not defined... On the other hand, we see from the form of the principle as derived formerly that the energy of a system remains constant, if a process carried out with the system does not cause any external effect whatever the internal effects may be. This observation leads us to conceive the energy contained in a system as a quantity existing independently of the external effects." And later: "Meanwhile it is unmistakable... that with this substance-like interpretation of the energy we get not only an increase in the conceptual clearness but also a direct progress in the comprehension... However, as soon as one enters into this question, the uncertainty, which lay before in the concept itself, takes upon the form of a physical problem which in principle can be solved..."

This solution came a few years later by Gustav Mie [2]. He showed that the principle of energy conservation can be formulated locally, namely in the form of a continuity equation. From then on, the strange separation of the system and the effects that can be observed only in the environment was no longer necessary.

Thus, it took about 50 years to prove the substance-like nature of energy. However, the expectation that the quantity had this property was there from the beginning: Ostwald [3] in his 1908 booklet, *The Energy*, praised the work of Robert Mayer with the following words: "For our general investigation the essential result of Mayer's work is the substance-like view of what he calls force, i.e. the energy. For him this was a welldefined entity; the indestructibility and unproducibility are characteristic for its reality."

Disposal:

We state the conservation law of the substance-like quantity X in the following way: "Energy, momentum, angular momentum, electric charge ... cannot be produced and cannot be destroyed."

Just as important are statements about the non-conservation of a substance-like quantity, for example: "Entropy can be produced but cannot be destroyed."

List of references

- M. Planck: Das Prinzip der Erhaltung der Energie. B. G. Teubner, Trennung, 1908, S. 115.
- [2] G. Mie: Entwurf einer allgemeinen Theorie der Energieübertragung. Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. CVII. Band, VIII. Heft, 1898, S. 1113.
- [3] W. Ostwald: Die Energie. Verlag Johann Ambrosius Barth, Leipzig, 1908, S. 59.

The energy conservation law

Subject:

The formulation of the energy conservation law does not seem to be trivial. The quotations (1) and (2) are taken from school books, and quotation (3) is from a university book.

(1) "The total energy of a body can be distributed among different forms of energy. – Without the transfer of energy to or from other bodies the total energy of the body remains constant"... "If several bodies are involved in the exchange and transformation without friction being present, the sum of kinetic, elastic and gravitational energy remains constant." ... "If friction is taken into account, the internal energy of the bodies and of the environment are part of the energy sum."

(2) "Theorem of the conservation of mechanical energy: In an energetically isolated system the sum of the mechanical energies remains constant, as long as the mechanical phenomena take place without friction. Energy is never lost, nor does new energy come into existence; it transforms from one mechanical form into another.... According to this theorem there exists a state variable for an energetically isolated system, called mechanical energy, which can appear in different forms, whose value is always conserved. Therefore, the energy of such a system is a conserved physical quantity."

(3) "Now the energy law can be formulated as follows: The amount of heat ΔQ supplied to a system from the outside serves to increase its internal energy ΔU , e.g. its temperature... or its electrical or chemical energy, and serves to realize the work ΔW , which we will consider negative when it is delivered by the system, so that

 $\Delta U = \Delta Q + \Delta W."$

Deficiencies:

A simple fact is described in such a way that it is hardly possible to recognize its simplicity. One might argue that before formulating the energy theorem, much has to be taken in consideration. However, one should eventually pronounce it in all clarity: Energy cannot be produced or destroyed. And there should be no qualms with this sentence. Otherwise the idea unavoidably comes up that conservation itself is a difficult concept.

Origin:

See the article "isolated systems" in this paper.

Disposal:

Formulate energy conservation in the same way as the conservation of electric charge, i.e. without any ifs or buts, for instance as follows: Energy can neither be created nor destroyed.

Internal energy and heat

Subject:

If heat is supplied to a body, then the body will contain more heat. If the body delivers heat, then at the end it has less. A person who is not educated in physics will surely not object to these statements. However, physics teaches us that they are incorrect: One can supply heat to a body, but thereafter it has none, and although it does not possess heat, one can extract heat from it. It looks like magic. The top hat is empty, but out of it comes a rabbit. Physics tells us that supplying or extracting heat does not change the heat content of a system; it changes the internal energy or enthalpy, depending on how the heat is supplied. The fact that energy is not called heat as soon as it arrives in the body is more than just a convention. There simply is no means to tell how much heat is contained in a body. In physics text books, this irritating circumstance is expressed in different ways. Some authors express it courageously [1]. Others risk doubtful justifications by maintaining that the internal energy can be divided in fractions, which they themselves would be unable to quantify [2], [3] (see also [4]). Sometimes heat and internal energy are simply taken to be identical [5].

Deficiencies:

I cannot imagine that even a single pupil will understand why it is incorrect to say that the heat supplied to a body remains inside the body. Most of our university students also would be unable to give an explanation. The statement appears to the student either only as sophistry, or it is memorized together with the numerous topics that one does not understand, and does not necessarily need to understand.

Origin:

For the description of the heat supply to a body one would need a quantitative measure of heat. The "heat" of the physicist as a "process variable" [6] is as poorly suited for this as the internal energy or the enthalpy so beloved by chemists. See also [7], [8].

Disposal:

It is particularly simple. One describes the process with the entropy. Entropy corresponds exactly to a non-physicist's idea of heat. If one heats something up, one supplies it with entropy, and after the entropy is supplied, the entropy is in it. It is easy to give a value for how much entropy is within a body, and still easier to quantify how much the entropy changes when warming the body up [9].

List of references

- [1] Galileo 9 (Oldenbourg 2000) p. 98: "Warning! Differentiate very carefully between heat, internal energy and temperature: An object does not possess heat, but internal energy!"
- [2] Spektrum Physik (Schroedel Velag Hannover 2000) p. 17: Under the heading "the portions of the internal energy" are specified: the kinetic energy of the particles; the energy, which is in the co-operation of the particles; chemical energy and nuclear energy.
- [3] Galileo 9 (Oldenbourg 2000) p. 93: "The energy of an object, which is not to be described as mechanical energy (potential or kinetic energy), one calls internal energy E_i. The atomic energy, the chemical and the biological energy all belong to the internal energy. A substantial portion is also the energy which is connected with the temperature of the object."

- [4] G. Job, Energieformen in Altlasten der Physik, Aulis Verlag Deubner Köln, 2002, p. 11.
- [5] Metzler-Physik (Metzlersche Verlagsbuchhandlung Stuttgart 1988) p. 60: "In all of these cases the bodies are performing frictional work; thereby a part of this mechanical energy is transformed into an energy form that cannot be transformed back into mechanical energy, but is given away as heat energy or internal energy to the environment inside or outside of the system."
- [6] F. Herrmann: State Variables
- [7] G. Job: Equivalence of Heat and Work
- [8] G. Job: Entropie in Altlasten der Physik, Aulis Verlag Deubner Köln, 2002, p. 85.
- [9] F. Herrmann: Die Messung der Entropie in Altlasten der Physik, Aulis Verlag Deubner Köln, 2002, p. 87.

Computational Modeling Issues in and around Physics Courses: Why, What, How and Whither?

Introduction to the GIREP-2006 symposium on Computational Modeling Issues for Physics Courses

Norman Chonacky American Institute of Physics 15 September 2006

I come here as the editor in chief of a technical magazine: *Computing in Science and Engineering (CiSE)*. This is a co-publication of the **American Institute of Physics** (AIP) and the **Institute of Electrical Engineers** (IEEE), in particular its Computer Society, so *CiSE* is committed to serve a very broad range of professional constituencies. Let me explain why this "marriage" of professional interests is not so odd as it may seem at first, and further why we believe this GIREP-2006 meeting is an appropriate forum in which to present this symposium. In doing so I will both introduce the contributors to follow and also provide a context in which their presentations can be understood. In my view physics is a universal "vocabulary" and computing a universal "methodology" that together underpin today's diverse scientific and engineering professions. As our first editor in chief, George Cybenko, put it eight years ago at our founding:

"CiSE is setting up camp at the confluence of two great intellectual rivers—the physical sciences and the computational sciences. This camp will grow into a town and then a city but only if we learn each other's languages and trade in good faith."

Ideally then, *CiSE* is designed to be a conduit connecting diverse scientific, engineering, and computing fields. It is a place where both computational methodologies and computational applications to science and engineering can be published in forms understandable to all these communities.

Computational modeling and simulation are two of the most successful methodologies that have been applied to sciences and engineering research and development work. Unfortunately, undergraduate physics programs, at least in the United States, do not reflect this reality to the extent that computational modeling is not a substantial part of the curriculum in most schools.

What evidence is there that these programs are not doing an adequate job in computational areas? Take a look at this graph (Figure 1) that was compiled from the results of a survey of physics bachelor degree graduates conducted by the AIP's own Statistical Research Center a few years ago. ["The Early Careers of Physics Bachelors" (August 2002) AIP Statistical Research Center report R-433

http://aip.org/statistics/trends/reports/bachplus5.pdf] I believe that these graphs indicate that training in scientific software and in computer programming suffer from the largest gaps between educational preparation and workplace importance.

Having read this report at the beginning of my editorship and recognizing in it a potential cause for *CiSE* to address, I took it to my editorial board and asked them if they felt this was a problem worth tackling. They agreed, and so I undertook creation of an editorial initiative, which I like to refer to as a "campaign."

I should reiterate at this point that *CiSE* is a magazine, and not a journal. An important difference is that a magazine can be an advocate because, in addition to considering unsolicited manuscripts for publication, unlike journals we can and do solicit them regularly both for our features and for our departments. Solicited papers form the majority of what we publish. So we can promote and support specific causes.



Figure 1: Time spent on tasks compared to rating of physics bachelor's educational preparation.

What are the rationales for assuming that *CiSE* has any business pursuing this cause at this or any other point in time? First, computational modeling is a cross-disciplinary issue; and our constituents are distributed across many disciplines. Second, education is one of our venues - CiSE publishes an education department article in each issue; but also our role as a conduit among disciplines gives us a tutorial function. Third, the time for doing this is now. Numerical modeling is now a predominant part of science and engineering work. Schools have unprecedented computing

power available accessible right from the desktop. And cross-disciplinary problems are rapidly becoming both common and pressing. Finally, as incoming editor-in chief of *CiSE* last year, I happened to have a blend of professional experiences that suited me to manage such a task. Trained as an experimental physicist, I had been in succession a physics professor, then a science researcher, and finally an engineering researcher in several different fields.

With this background in mind, I now wish to move back to the notion of a campaign whose objectives are to advocate and support the integration of computation into undergraduate physics courses. This campaign has three parts:

Partner with professional associations

Provide a voice and platform to air relevant issues and discussion

Host refereed, broad-spectrum articles in this area

Let me outline what we have done thus far leading up to and including this symposium.

In the summer of 2005, CiSE partnered with the American Association of Physics Teachers (AAPT) – a rough equivalent of the GIREP – to sponsor an informal discussion on the state of computation in undergraduate physics courses at the AAPT national meeting at the University of Utah. The concept of this discussion was to gather together a small group of physics professors that we knew to be early and dedicated developers of computational practice at their institutions. As such we specifically invited ten of such instructors to what otherwise was a gathering open to any of the meeting attendees. In all about twenty participated representing a blend of old and new faces. The "grass roots" discussion that ensued thus represented a blend of established and new wisdom. There emerged two conclusions to which all could agree. One was that we needed a broader national discussion on the issues. The other was that we needed a concrete data sample on actual computational physics practices in courses nationwide.

As the editor of CiSE, I was able to commission a national survey of current practices, which took place in the autumn of 2005. Just after I finish, Professor Robert Fuller will describe this survey and present his analysis of the data collected.

On the basis of this survey, we were able to identify individuals in over 250 colleges and universities in the US who were sufficiently concerned about computations in physics courses to tell us what they were, and in some cases what they wish they were, doing in this area. Further, we were able to identify four major paradigms for the degrees and quality of computational uses in undergraduate courses. After Fuller, Professor David Winch will describe these paradigmatic classes and list examples of participants that were placed in each.

Using these paradigms as a guide to segregate survey participants, we placed each into one of four classes. Then we selected one person from each class for invitation to describe her/his work at the summer 2006

AAPT summer meeting at Syracuse University. Moreover, we solicited an article from each of these to include in a *CiSE* special issue on the theme of "Computation in Physics Courses," published coincidently at the time of this GIREP meeting in the *CiSE* September/October issue. There should have been a copy of this issue included in each of the registration packets for this GIREP meeting. Both Fuller's and Winch's papers in that issue are the bases for, and good references to, their respective presentations in this symposium.

In addition to the four Syracuse University presentations, we invited twenty more of those survey respondents who appeared to be really committed to redress the underuse of computation in physics courses to present posters that would be grouped at this meeting. Both the invited speakers and the invited poster presenters were invited to a working dinner on the eve of their presentations. At this dinner, in keeping with the second consensual item of the previous summer's gathering, we arranged to have structured discussions to extend the deliberations of the previous summer and hence enlarge the airing of relevant issues. This discussion provided an extraordinary perspective from which we could interpret our survey data. Among other realizations was an indication of a strong desire to shape a national agenda for developing and disseminating materials that embed computation into the standard canon for undergraduate physics. The participants felt that this would legitimate their efforts to do so and thus give professional credit for working in this area. Such credit is already granted by a small number of institutions but needs to be expanded to others if we are to have a rich variety of types and approaches of validated materials.

Yet "one size fits all" is not likely to be a solution to the wide range of contexts into which computation in physics curricula in the coming generation must fit. While we are sorting out a new canon, we need media in which peer refereed work may be published so that appropriate professional credit can be given to competent offerings. We also need some leadership and forums to present, debate, and refine developments in the area of computational physics education.

This symposium is one effort to provide such a forum. By inviting two distinguished leaders of efforts to conduct computational physics education to this symposium, we are framing two ends of the discussion that have yet to be addressed. Professor Cees Mulder will present a perspective on what is being done in the Netherlands to implement a computational physics model for pre-university contexts. One should keep in mind that the educational systems in Europe and the US are not synchronized so that his remarks can apply to the first year undergraduate programs in the US as well. After that, Professor Hans Bungartz from the Technical University in München will describe his efforts to provide meaningful post-graduate education in computational science that, in a sense, represent a model post-university implementation of computational physics.

I hope that this combination of US and EU examples will provide a fruitful basis for furthering efforts to improve computational physics in both regimes. I can say personally that I am looking forward to this symposium for this purpose, and am grateful for all the contributions of all the presenters and for the opportunity that GIREP has provided us for this "cross-cultural" exchange. Thank you!

How Much and What of Computing for Physics Education?

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Abstract

In this contribution, we try to depict how the future undergraduate physics education should take into account the increasing computational flavor in science and engineering, observed in both academia and industry. This flavor, of course, has its roots in mathematical modeling and numerical simulation, but it has got a much broader scope in the last years, including issues of visualization, parallel and distributed processing (up to the Grid), data handling and exploration, and software engineering. Hence, this paper's core statement is that the modern physicist needs more than a mere programming course or some basic numerical knowledge, but a profound education and training in "Advanced Computing" – organized in a way similar to the typical Advanced or Higher Mathematics Courses covering calculus and linear algebra which are close to standard today.

Introduction and Background

Today, Computational Sciences are generally considered to be a – if not *the* – key technology of the future [see (Benioff & Lazowksa, 2005), e.g.]. Actually, on the research side, it is obvious that in many fields of science and engineering gaining new insight is closely related to the use of computer-based methods. Physics (which we will take as our example in the remainder) and mechanics are two prominent representatives for this development. However, on the education side, changes seem to be much slower. Although there are quite a lot of new specialized and tailored programs such as CSE or Computational Physics (especially on the graduate level), there are several evident problems. First, the computational aspect in such programs is often simply covered by focusing on modeling (which, actually, is just theoretical physics and not a really computational feature), by some mere introduction to programming, and by a small selection of extremely physics-oriented numerical topics, typically presented by (computational) physicists within their standard courses – mathematicians and computer scientists stay outside. Hence, second, topics such as distributed processing, visualization, data exploration, or software engineering are more or less ignored and left over to some later "training on the job". Finally, the classical bachelor's programs in physics are rather reluctant to modifications anyway – rigid regulations and the "What to omit instead?" argument are frequently preventing new courses from being introduced. Recently, however, voices also from inside physics [see (Post & Viotta, 2005), e.g.] have pointed out that changes are crucial, that producing

reliable simulation software means much more than the mere act of putting some mathematical model or the numerical algorithm derived from it into code.

What is said in the remainder of this contribution, to some extent, is an external or non-physicist point of view. However, it is based upon year-long experiences in the Computational Sciences education. Since it seems to be a general observation that Computational Physics programs are organized in a more mono-disciplinary (i.e. physics-based) way than CSE education is done (at least in Germany), it might be a good idea to look what lessons have been learned or still are to be learned there when thinking about "computational updates" of undergraduate programs in physics.

Experiences and Observations

In this section, we briefly summarize our experiences with the interdisciplinary education in Computational Sciences and mention some interesting observations often made there.

Classical physics programs

Our group is responsible for the 2-semester course "Introduction to Programming" for beginners in physics at TUM. The idea is to provide a solid basis (Maple plus one programming language such as C, C++, or Java) for later computational activities. Though the students are in their first year and, hence, do not yet have the mathematical background typically required for a numerical course, we have given our course some numerical flavor, i.e. providing more or less an introduction to *numerical* programming. At present, "Introduction to Programming" is the only mandatory part in the physics curriculum imported from the computer science department (as well as from the math department apart from "Higher Mathematics"). Physics students tell us that, after this introduction, they get a bit of numerical education here and there – always integrated into some topical course – but nothing systematic, and that's why quite a lot of them, later, choose elective courses on scientific computing at our chair.

Computational X programs

Experiences on the graduate level stem from the interdisciplinary master's programs "Computational Mechanics of Materials and Structures" at Universität Stuttgart, "Computational Mechanics" and "Computational Science and Engineering (CSE)" (CSE, 2001) at TUM, as well as the Bavaria-wide honors program "Bavarian Graduate School of Computational Engineering (BGCE)" (BGCE, 2005). The latter two, for which the author is responsible at present, are hosted by informatics departments, but they are, nevertheless, designed in a really multidisciplinary way. TUM's CSE program, e.g., is a joint venture of seven of TUM's departments (informatics, mathematics, physics, chemistry, civil engineering, mechanical engineering, and electrical engineering). There, we try to focus on the *methodical* part of Computational Sciences or simulation technology (i.e. numerical programming, parallel and supercomputing, as well as all of the "enabling technologies" such as algorithmics, software engineering, or visualization) without neglecting the *application* part. Actually, students get in contact with two classical fields of application of numerical simulation (physics, chemistry, biosciences, structural mechanics, fluid mechanics, microelectronics, ...), but these are not in the centre of interest. Our applicants typically have a bachelor's degree in one of these fields of application, and they want to get this additional computational flavor in their education which this paper wants to promote to get also implemented in classical programs – at least to some extent. TUM's CSE master's program has been running since 2001 – hence, there is no relevant statistics available yet, but experiences and feedback (from teachers, students, and employers) so far are very positive.

Co-operations

The Garching campus north of Munich does not only host TUM's departments of mathematics, informatics, physics, chemistry, and mechanical engineering, but also the neutron source research reactor, the physics department of Ludwig-Maximilians-Universität, four Max-Planck-Institutes for physics (astrophysics, extraterrestrial physics, quantum optics, and plasma physics), the European Space Observatory, the nation-wide computing centre of Max-Planck society, and the Leibniz Computing Centre of the Bavarian Academy of Sciences, hosting one of Germany's three federal supercomputers. Hence, it is guite natural that in such an environment there are a lot of research activities in computational physics. Just to mention a few examples, there are several Grid projects concerning the Virtual Space Observatory, there are Grid activities for the Large Hadron Collider at CERN, and there is an abundant variety of numerical simulation projects (cosmology, accelerator technology, etc.). One of the central messages we receive and learn from these networks and projects is that modern physics needs expertise in fields such as data exploration or Grid technology – classical subdomains of informatics having got this enabling character for (Computational) Physics.

Innovative course modules

Introducing new topics in new or modified lectures is one part of the story, but we also have to think about new types of courses. Most strategic papers dealing with Computational Sciences [see (Post & Viotta, 2005) and (Benioff & Lazowksa, 2005), e.g.] emphasize that the software issue will probably be the bottleneck and, hence, the challenge of the future (replacing or, at least, joining hardware and algorithmics). How to get high-quality software, how to professionalize the design and implementation process, and how to educate people who are sensitive and

well prepared for improving the situation? One possible course model we reported in (Bernreuther & Bungartz, 2006) and which turned out to be both motivating for students and highly effective are the student projects we took over from the Software Engineering curriculum at Universität Stuttgart and we implemented in the BGCE curriculum (BGCE, 2005). There, 4-8 students work together for 6-9 months on designing and implementing a complete piece of simulation software from the scratch. The desired functionality is given, an advisor provides support, and a "customer" checks whether the contract (milestones, deadlines, beta versions etc.) is fulfilled. For the internal organization (giving roles such as the project manager, implementing teamwork, enforcing deadlines, ensuring quality control etc.), help is given, but this all is, primarily, the team's job. Obviously, the experience of doing it is much more in the focus than the product itself (topics so far have been a Virtual Wind Tunnel, Molecular Dynamics, and Geometric Modeling) is – which is untypical, but which turned out to be very helpful for learning the process of writing simulation software instead of just hacking code. Our experiences with these team projects are very good, but it is, definitely, just one way how to take into account the computational challenges in education in an appropriate way.

Theses on the Why, What, Where, How, and Whither

In this section, we want to directly address the central questions of the symposium. Thus, based on our experiences, a possible way how to adapt bachelor's programs in physics is depicted. As already mentioned, this has to go beyond the mere fostering of modeling and simulation in physics.

Why changes?

The increasing influence of computing is neither comparable to some new kind of physics which may be postponed to the graduate level, nor is it dealt with seriously by simply saying that smart physicists won't have any problems in working with a computer if they are good in physics. It, rather, represents a new and rapidly changing way of working in physics – which must be taught as early and as intense as necessary.

What changes?

The changes must be demand-driven – to avoid the errors done with the math education. Physics must provide the list (which, probably, should contain at least a solid training in programming, an introduction to numerical analysis covering classical discretization techniques as well as particle methods or Monte Carlo approaches, visualization, at least fundamentals in data base technology, an introduction to high-performance computing, and – at least as an elective topic – fundamentals of software engineering), but mathematicians and computer scientists must provide the courses.

Where to change?

Everywhere and on all levels. Specialized programs in Computational Physics, e.g., are important and often easier to implement, but they can not replace changes in the standard Physics programs. We need a topical face-lifting, and we need another step beyond the borders of the physics departments (as it was always done with the basic math education). Trans-disciplinarity does not mean only that one discipline starts thinking about topics from outside – there has to be a real co-operation between disciplines and the respective people, in research and education.

Where to head for?

In my feeling, time has come for basic undergraduate courses in "Advanced Computing" (or call it "Advanced Informatics" or ...), comparable to the math education. At Germany's technical universities, there is a long and successful tradition of a 3-4-semester cycle in "Higher Mathematics", compulsory for all engineering fields and physics (if students of physics do not share the courses with mathematicians) and with a selection of topics tailored to the respective needs. A comparable cycle "Advanced Computing" for beginners of, say, three courses with lectures, tutorials, and a practical/lab part could be offered by the computer science department and bundle all the aspects identified as crucial for a modern (and that is computer-oriented) physics education. Additionally, a group project comparable to the experiences in (Bernreuther & Bungartz, 2006) on a topic from computational physics (designing and implementing an elementary molecular dynamics package, e.g.) could bridge the gap between those advanced computing technologies taught and the main objective to solve problems from physics. Of course, this would imply that some credits are saved elsewhere, but this is not necessarily dramatic, since the existing courses or modules dealing partially with computing-relevant aspects could be skipped or reduced.

Concluding Remarks

This contribution presented some ideas how to re-shape the undergraduate (computational) physics education in order to take into account the increased importance of computing, and how to design innovative project-style courses to effectively teach more softwarerelated topics. The concepts suggested are mainly based upon experiences made in the Computational Sciences education.

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Action on Stage: Ways to Unify Classical and Quantum **Physics Using the Action Model**

Action on Stage: Historical Introduction⁷

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Abstract

The action principle is a powerful tool for understanding, applying, and building bridges among fields of physics, from quantum theory through relativity to current research. We dramatize those who devised the action principle and its precursors - Fermat, Huygens, Maupertuis, Euler, Hamilton, Einstein and Feynman – with the authors performing the roles of these great physicists and mathematicians. We accept no responsibility for the accuracy of the words of our characters! This is an effort to introduce fundamental physical principles, not to reconstruct the actual historical development of these principles.

Action on Stage

Animateur:

This symposium is about building bridges between things students would like to learn-relativity, quantum theory, particle physics – and things they have to learn – notably classical mechanics. We are interested in simplicity and unity in physics, as well as with exciting students about physics.

The idea that links these topics is the concept of stationary action.

Pierre de Fermat

Now we have a problem. Either you know nothing at all about the physical quantity called *action*, or you learned it in a difficult course of theoretical mechanics. Both will make you hostile to our proposals. Either, "I never studied it, so it can't be important", or "Anything I don't understand *must* be too hard for students".

⁷ All pictures were taken from The Mactutor History of Mathematics archive at the website http://turnbull.mcs.st-and.ac.uk/history in the biography index item.

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So – we have to tell you about these ideas, starting from zero. How better than to ask the people who invented them to explain what they were doing? First up is the Frenchman Pierre de Fermat.

Pierre Fermat (1601-1665):

Although I never published a scientific paper, my reputation as one a leading mathematician came from my correspondence with other scientists and from them publishing my ideas and methods in their work. I am known primarily for my work in number theory. I also developed analytic geometry independent of Descartes and worked in many other mathematical fields – completely as an amateur.

I had a terrible fight with Descartes. He thought that light is transmitted instantaneously from point to point "like the cane of a blind man," so I had to express my optical theory in terms of "resistance" of different media through which light passes. You have no such difficulty, and Fermat's principle of least time is the oldest variational principle; one that you still use. The idea is simple: the path that light takes is just the one that takes the least time. Among all possible paths, the minimum total time picks out the unique path between fixed initial and final points. What could be easier?

Animateur:

Monsieur Fermat, there's an obvious objection to your idea. How does the light know in advance which path will be the quickest?

Fermat:

When I was alive I could not answer your question. The objection was not overcome until long after my death, when you came to see that every point on an advancing wave acts as a source of little wavelets. Then between point source and point detector the wavelets add up with coherent phase along *the path of stationary time*. I hope you will tell us how some Dutchman figured it out.

Animateur:

We had hoped that, as a Dutchman, Christiaan Huygens could join us here in Amsterdam, but unfortunately he is away at the Royal Court in France. His big idea was that light is a wave, and that where the wave goes next can be predicted by supposing that each point on the wave front acts as a source of little wavelets. The many wavelets all superpose, adding up in constructive interference to generate the new wave front, but canceling in



Christiaan

destructive interference everywhere else. Centuries later, Richard Feynman was to adapt the same idea to build a new formulation of quantum mechanics: the "many paths" approach. Now we jump a hundred years, and our next guest is another Frenchman, Pierre Louis de Maupertuis.

Maupertuis (1698-1759):



I am Pierre-Louis Moreau de Maupertuis. My father, a wealthy pirate, gave me every advantage. I led an expedition to Lapland to measure the length of a degree along the Earth's meridian, proving that the Earth is hamburger-shaped. Its fame led to my becoming president of the Prussian Academy and a favorite in the court of Louis the fifteenth.

Pierre de

I conceived the principle of least action, that in all events of Nature there is a certain quantity,

called *action*, which is always a minimum; that collisions of bodies or refraction of light occur in such a way that the amount of the quantity *mvs* is as little as possible. My original definition of action as the product of mass, speed and distance traveled by a moving object was later restated by my friend Leonhard Euler [see eq. (1)].

My paper was titled, "The laws of motion and rest deduced from the attributes of God" and stated: "Here then is this principle, so wise, so worthy of the Supreme Being: Whenever any change takes place in Nature, the amount of action expended in this change is always the smallest possible." I am horrified to hear that people think that action can sometimes be a saddle point; I reject this idea entirely because the perfection of God is incompatible with anything other than utter simplicity and minimum expenditure of action.

Animateur:

Ignorant people say that nothing of intellectual distinction greater than the cuckoo-clock ever came out of Switzerland. To give them the lie, we now hear from the great Swiss mathematician Leonhard Euler, who supported and developed Maupertuis' idea.

Leonhard Euler (1707-1783):

It is no boast to say that I am the most prolific mathematician of all time, producing about 900 papers and books in my lifetime. I spent my years largely in the courts of the Tzars of Russia and in the court of Frederick the Great.

Maupertuis is a great buddy of mine, but sloppy in formulating his action principle. I realized that



Leonard Euler

without the law of conservation of energy the action quantity of Maupertuis loses all significance. So I cleaned it up, formulating the principle of least action as an exact dynamical theorem and giving his action a correct mathematical form:

$$W = \int_{\substack{\text{position}\\\text{position}}}^{\text{final}} mv \, \mathrm{d}s \qquad \text{(assume energy conserved),} \qquad (1)$$

(The integral is calculated along a path of a moving particle.)

My statement "since the plan of the universe is the most perfect possible and the work of the wisest possible creator, nothing happens which has not some maximal or minimal property!" was my acknowledgement of Maupertuis as originator of the action principle.

I also developed a simple, intuitive, geometrically understandable way of finding the minimum or stationary action path (see figure 1)



Figure 1: Euler realized that if the action integral is minimal along the entire path, it must also be minimal for every subsection of the path: triplets of nearby points on the path, e.g. mno in my figure. Minimal action means that any change in the path, e.g. point n varied slightly to point v, leads to zero first order change in action. If this condition is be satisfied for each triplet and we go to the limit in which lengths of segments tend to zero, we get a differential equation (the Euler-Lagrange equation), whose solution is the stationary action path.

Later, I helped the career of the young Joseph Louis Lagrange (1736-1813), who wrote to me about his elegant mathematical way to express conditions of minimum action. His ideas led me to drop my intuitive graphical approach and coin the phrase "calculus of variations". Great for mathematics and theoretical physics, but a disaster for physics education! Lagrange's abstract method has dominated your advanced mechanics classes. Too bad, because my graphical method is perfect for modern computers (fig. 2)



Figure 2: The universality of Euler's graphical approach is demonstrated by this computer display used in modeling Fermat's principle. Click the computer mouse to select an arbitrary moveable intermediate point on the path, then drag the point up and down, looking at the value of the total time, to find the minimal (stationary) time of that point. Then do the same for other points, cycling through them until the time for each results in the least (stationary) value of the total action or time. This method of successive displacements or hunting for the least time path is straightforward but tedious. However the task can be done quickly by computer.

Animateur:

We jump a hundred years again. Here is the Irishman William Rowan Hamilton to tell you about his new version of action, more powerful than ever.

Hamilton (1805-1865):

My name is William Rowan Hamilton. I wanted to develop a common mathematical language for particles and waves, so starting from Fermat's least time principle and using the Lagrangian, I found what you call Hamilton's action *S*:

$$S = \int_{\substack{\text{initial}\\\text{event}}}^{\text{final}} L \, dt = \int_{\substack{\text{event}\\\text{initial}\\\text{event}}}^{\text{final}} (K - U) \, dt$$
(2)



William R.

Maupertuis' action, remember, determines *trajectories in space* between fixed initial and final locations and requires that energy be conserved. In contrast, my action principle determines *worldliness in space-time* between initial and final events and is true even if the potential energy is a function of time as well as position, in which case the energy of the particle may not be a constant. I understood that action along an actual worldline is not necessarily a minimum but is always stationary compared

with action along adjacent alternative worldlines between the same fixed initial and final events. Actually the word "worldline" is a stranger to me; it took Albert Einstein to make the term important. For me it was just the path between fixed places and times – between what Einstein called fixed *events*.

Einstein:



I, Albert Einstein, am Swiss by nationality – another blow to cuckoo-clock theory! It was my idea that the physical world has to be structured as space-time events. I emphasized the fact that such events are connected by worldlines in space-time. I could show that the natural, unforced, path from one event to another was that for which ageing – wristwatch time – is a maximum.

Albert Einstein particle is just:

In relativity, the Hamilton action S for a free

$$S = -mc^{2} \int_{\substack{\text{initial}\\\text{event}}}^{\text{final}} d\tau$$
(3)

Minimal (or stationary) action along a real worldline makes the total proper time $\tau = \int d\tau$ maximal (or stationary). Therefore, because of the minus sign in front of the integral, the relativistic principle of least action is the same as the *principle of maximal proper time*, called by Dr. Taylor the *principle of maximal aging*.

Moreover it is not difficult to show that for small velocities Eq. (3) gives the same results as classical nonrelativistic Hamilton action.

Animateur:

You will have noticed that these contributions all came from Europe. But in the last century, American physics blossomed, and one of its finest products was Richard Feynman, who completes our story.

Richard Feynman:

When I was in high school my physics teacher Mr Bader told me that Newton's laws could be stated not only in the form F = ma, but also in the form: "average kinetic energy minus average potential energy is as little as possible for the path of an object going from one point to another." I next got involved with least action as a PhD student with John Archibald Wheeler. This led to the development of the "many paths" version of



Richard

quantum mechanics, a third formulation mathematically equivalent to the Schrödinger and Heisenberg versions. It also helped me develop my *"Feynman diagrams"* for doing calculations in quantum electrodynamics. For this work I shared the Nobel Prize with Schwinger and Tomonaga.

So how does a mindless particle recognize the least action path or worldline? Does it smell neighboring paths to find out whether or not they have increased action? According to my formulation, yes! The electron explores all worldlines between source and detector. For each possibility there exists a little rotating stopwatch whose hand, or *arrow*, makes a total number of turns equal to Hamilton's action *S* divided by Planck constant h (see Fig. 3). The Lagrangian L, divided by h, is nothing other than the rate of arrow rotation.



Figure 3: In the "many paths" version of quantum mechanics the electron explores all possible worldlines from initial emission event to final detection event. The figure shows a single one of these worldlines. Along this path a little stopwatch hand rotates at the rate L/h, leading to a contribution to the final amplitude at the detection event.

All these quantum arrows (probability amplitudes) add up constructively (*line up*) if they have similar phases. This is so for worldlines close to the stationary action path (the blue pencil of paths in Fig.4). The arrows cancel out or *curl up* for other sets of worldliness, as you can see in a piece of Dr. Hanc's program. The bigger the mass of an object the narrower is the pencil of nearby worldlines that significantly contributes to the resulting amplitude.

Animateur:

Christiaan Huygens has sent me a letter claiming priority for your "many paths" idea. He claims that it is just his idea of wavelets, in modern clothing. What do you say to that?



Figure 4: Some of the infinite number of possible worldlines connecting fixed initial and final events. The squared magnitude of the resultant arrow is proportional to the probability of detecting the particle at the final event. As the particle mass increases, the pencil of worldlines contributing significantly to the resultant arrow (shown in blue) becomes narrower and narrower, approaching the single path of classical mechanics.

Richard Feynman:

It's true (I acknowledged Huygens in my PhD thesis). However the use of Planck's constant, and the fact that the idea also works for particles like electrons or atoms, goes beyond Huygens. The idea for the number of quantum stopwatch rotations came from Paul Dirac.

Animateur:

OK, that's it. We will be describing in the papers that follow, how the scalar quantity *action* adds to the physicist's toolkit for analyzing and predicting motion. It looks like this:

- 1. Use Maupertuis action *W* when we fix in advance the initial and final POSITIONS, and energy is conserved.
- 2. Use Hamilton action *S* when we fix initial and final EVENTS and energy is may or may not be conserved.
- 3. Use Newton or Lagrange when we do NOT know where the motion is going from its initial conditions.
- 4. Use Newton when friction is significant, so vectors are inevitable.

We hope that we have started to break up some of your thought-glaciers about action.

References

Background papers with historical references are available at the website:

http://www.eftaylor.com/leastaction.html

A First Introduction to Quantum Behavior

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Abstract

The physics curriculum in England and Wales has a requirement to introduce quantum phenomena to students in the first year of the twoyear pre-university physics course in schools. Usually this means discussing the photoelectric effect, with a few words about "waves or particles". In the innovative course "Advancing Physics" we take a more fundamental approach, following Feynman's "many paths" formulation of quantum physics. The experiences of teaching this material for the past five years are discussed, together with difficulties it has thrown up.

Introducing quantum behavior: a national requirement

In England and Wales, all "A-level" Physics courses – that is, high school physics courses leading to University entrance are required to introduce the quantum behavior of photons and electrons. For the innovative course *Advancing Physics* (Ogborn & Whitehouse 2000) we decided to base our approach on Richard Feynman's remarkable small book "QED" (Feynman 1985), in which he describes in the simplest possible terms his 'sum over histories' or 'many paths' approach to quantum mechanics. Others have tried something similar (see Hanc et al 2005).

The Feynman approach in essence

"...Dick Feynman told me about his ... version of quantum mechanics. "The electron does anything it likes," he said. "It just goes in any direction at any speed, forward or backward in time, however it likes, and then you add up" I said to him, "You're crazy." But he wasn't.'

Freeman Dyson

Feynman's big idea, starting with his 1942 doctoral thesis (Brown 2005), was to track all the space-time paths available to photons or electrons in a given situation. Every possible path is associated with a quantum amplitude. To find the probability of an event, you add up (taking account of phase) the amplitudes for all possible paths leading to that event. The probability is then given by the square of the amplitude, suitably normalized. The phase of the amplitude is given by a result first noted by Dirac, namely that the number of rotations of the phase 'arrow' along a path is just the classical action *S* along the path, divided by the Planck constant *h*.

This alternative way of setting up quantum mechanics led to enormous simplification of calculations in quantum field theory, and is still today an essential tool for theoretical physics. Our concern, however, is with the simplification and clarification it can bring to a first introduction to the quantum world.

Six steps in introducing quantum behavior

We think of our teaching program in six steps:

- 1. random arrival
- 2. photon energy in lumps of size E = hf
- 3. superposition of amplitudes
- 4. what is quantum behavior?
- 5. quantum behavior can explain
- 6. electrons do it too.

Step 1 Random arrival

Perhaps the most important first experience of quantum behavior is to listen to a Geiger counter detecting gamma photons: "click....click. click.....click". The key point is that the gamma photons arrive *at random*. The time of arrival of a photon is not predictable: the only thing we can know is the *probability* of arrival. Here is the first cornerstone of an understanding of quantum behavior: only the probability of events is predictable.

A well known set of photographs (Figure 1) illustrates the idea beautifully.

A more careful treatment would want to show that the arrival of photons follows a Poisson distribution, but this level of discussion is not available to us in this course, though we are working on it (Ogborn, Collins & Brown 2003a,b).

Step 2 Photon energy in lumps of size E = hf

The next step is to measure the energy and frequency to arrive at an estimate of the Planck constant h. We suggest the use of a set of lightemitting diodes (LEDs), measuring the wavelength of the light they emit, and the minimum potential difference needed for light just to be emitted.

The point is to get across, as simply and directly as possible, that whatever happens in between emission and arrival, light is always emitted and absorbed in discrete amounts E = hf. Now we have to think about "what happens in between".

Step 3 Superposition of amplitudes

In *Advancing Physics*, the study of quantum behavior follows a study of the nature of light. There, the classical story of the development of the wave picture is told, from Huygens and Fermat through to Young and Fresnel. Thus students know that interference effects arise when there are alternative paths between emission and absorption events. Now we marry up this wave picture of superposition with the story of quantum behavior.



Figure 1: The same picture taken with progressively more and more photons. The photons arrive randomly, but with probabilities such that the picture gradually builds up

The big idea of quantum theory can be put very simply. It is just: "steal the wave calculation but forget about the waves". That is, associate with each path a phase 'arrow', and add up the 'arrows' to get the resultant amplitude from all paths.

This is just Huygens' wavelet principle. But something new and essential is added. It is that the rate of rotation of the quantum arrow along a path is given by f = E/h. In this way, the results of the wave calculations of interference and diffraction patterns are all taken over. The novelty is to start with the photon energy *E* as given and fundamental, and to use *h*, the quantum of action, to translate it into a rate of rotation of phase.

Here we arrive at the heart of quantum behavior. In wave theory, the existence of a phase is a consequence of the nature of wave motion. In quantum thinking, the existence of a phase is rock-bottom fundamental. It is to be thought of as a given, not as a consequence.

Step 4 Quantum behavior

We can now describe the behavior of quantum objects. For each possible path between initial and final discrete events, there is an 'arrow' (a phasor). For photon paths, the rate of rotation of the arrow between start and finish is E/h. Add up the arrows for all the possible paths, tip to tail, to get the resultant 'arrow' for the pair of events. The square of the resultant 'arrow' is proportional to the probability of the pair of events.

Although initial and final events are localized, there is no reason to think of a photon as localized "in between". Lumpiness in energy does not imply lumpiness in space. To say as Feynman does that the particles "go everywhere" is not to picture them as trying out all the possibilities one at a time. Part of the essence of "being a particle", namely its continuing existence at a succession of places and times, has been taken away. Waves, of course, do "go everywhere", but part of their essence has gone too. Their energy can no longer be divided into smaller and smaller amounts, without limit.

Not surprisingly, this account gives students difficulties. Like most of us, they naturally try to form as concrete a picture as possible. So, thinking of photons as particles, and imagining tracking each along a given path, they wrongly imagine them trying out all possible paths one by one. They tend to think of the rotating phasor, not as associated with the *path*, but as 'riding on the back of a photon' as it travels.

However, these difficulties are simply the difficulties of getting used to quantum thinking. A possible merit of the approach is that it brings them out so clearly, by denying that photons are some mixed-up approximation to waves and particles. Thus we present quantum behavior as itself, not as like something else. Its essence is that all possibilities contribute, superposing taking account of phase.

Step 5 Quantum behavior explains...

We conclude by offering students some comfort, by showing how quantum behavior explains some familiar things, in particular, the laws of reflection and refraction.

Figure 2 shows a diagram from Feynman's book, illustrating how the law of reflection at a plane surface arises directly out of the quantum behavior of photons.

Every possible path from source to detector counts. But only in the middle are nearby paths closely similar in length, so that the 'arrows' associated with them are nearly in phase and thus 'line up'. Further out, the phase changes rapidly as the path changes, so that the arrows from these paths 'curl up', giving a very small contribution to the final resultant arrow. Only the paths very close to the path prescribed by the law of reflection make an important contribution.

This explains Fermat's principle of least time. The graph shows how the travel-time varies as the path changes. At the minimum the time does not vary as the path changes. So the phase associated with these paths does not change either. However, quantum thinking gives us something more. By thinking about *how much* the phase changes between
nearby paths we can estimate the limits to the description given by geometrical optics.

The traditional "wave-particle duality" story makes it seem as if wave and particle behavior are partial explanations of quantum behavior. Something more like the reverse is true. Particle behavior, in particular all of classical Newtonian mechanics *is explained by* quantum behavior (see Ogborn & Taylor 2005). Equally, the wave behavior of light *follows from* the quantum behavior of photons, in the limit of low photon energy and many photons. Quantum physics helps to explain why – and when – classical ideas work.



Figure 2 Reflection of photons at a plane mirror

Step 6 Electrons do it too

The description of quantum behavior is appropriate not just for photons, but for all particles, including electrons. For a free (non-relativistic) electron, the rate of rotation of the quantum arrow is just K/h, where K is the kinetic energy. Demonstration apparatus available for school laboratories makes it straightforward to show electron diffraction. Even better is to see electrons arrive one by one, building up gradually into a

two-slit interference pattern. This has been achieved by a Hitachi team led by Akira Tonomura, who have produced a beautiful film clip of this most fundamental experiment (Tonomura et al 1999).

The rate of rotation of the phase of an electron is given by L/h, where L is the Lagrangian, and the total phase rotation is S/h, where S is the action along the path. We don't mention this to students in *Advancing Physics*, but we mention it here to show how the simple approach can be extended in later work.

Does it work?

The only evaluation we have, so far, of the value of this approach is the experience of it being taught in about 25% of UK schools teaching physics at this level. The teachers have available to them an email network, to discuss whatever they please. Every year, when this topic is taught, there is a flurry of discussion, about what exactly the ideas mean and about how to respond to students' questions.

These discussions show that teachers new to the approach are understandably nervous, and need a good deal of re-assuring. It also shows that they, like their students, are prone to giving the ideas an overconcrete interpretation, particularly in wanting to associate a 'traveling phasor' with a 'traveling photon', rather than associating a phasor with a possible path.

Some ways of teaching the ideas lead very strongly to overconcrete interpretation. One popular idea is to push a rotating wheel along a number of paths and to note the total rotation for each path. This very effectively shows how, for example, the results of Figure 2 arise. But students inevitably want to know what role the wheel, and its diameter and speed, play in the theory.

However, it remains true that there is, in evaluation of the whole *Advancing Physics* course, no demand to remove or change this topic. Nor do students complain about the examination questions set on it. We can say, therefore, that this rather radical innovation has succeeded at least to the extent of having survived for six years so far, in a course taught on a national scale in schools of widely differing kinds. And at least a proportion of both teachers and students find it very interesting and thought-provoking.

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What is the action model? Introducing and modeling principles of least action.

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Abstract

The Action Principle predicts motion using the scalars energy and time, entirely avoiding vectors and differential equations of motion. Action is the tool of choice when we want to specify both initial and final conditions. Maupertuis-Euler action finds the trajectory when initial and final positions are prescribed in advance, but requires that energy be a constant of the motion. Hamilton action finds the worldline when initial and final events are prescribed in advance and easily describes motion when potential energy is a function of time as well as position. A simple toolkit of motion tells us when to use action, when to use Lagrange's equations, and when we must return to the vector methods of Newton. The original Euler method of handling action also provides a basis for computer modeling. Interactive software allows students to employ basic concepts of the principle of least action and increase conceptual understanding.

Least action approach in teaching

The least action principle approach, so important for modern physics, is widely considered to be a difficult topic and is usually only used in advanced mechanics textbooks and courses. Why does it seem a peculiar way to introduce and teach classical mechanics? Why is action as a physical quantity understood as being very abstract and unsuitable for introductory physics, despite the fact that it is a scalar very similar to energy – one of the central concepts of introductory courses?

The reasons are that in the majority of standard advanced texts [like Landau & Lifschitz 1976, Goldstein et al 2002, Marion & Thornton 2003, Hand & Finch 1998], — (1) the mathematics used is *the calculus of variations*, which is not part of the common mathematical toolkit acquired at introductory college level; (2) action is usually introduced extremely briefly and is only used for a quick variational derivation of Lagrange's equations; (3) action is not immediately illustrated by examples; texts typically include no or a very few examples; (4) there is also no study of the properties of action after introducing it, since they are taught at the end of courses and texts, (5) and finally you find no computer modeling, which means that students cannot obtain direct experience and intuition.

So the important question is how to introduce least action principles? Our experience says that it is possible in the frame of introductory courses provided that we concentrate on the following crucial issues:

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- *Starting with one dimensional cases and using a powerful graphical language*. More general cases only bring in more complicated mathematical expressions, but essentially nothing new in physics ideas
- *Using concrete, but easily generalizable examples.* We have chosen Newton's falling apple, but the arguments will work for any reasonable potential energy function.
- *Building a clear connection to Newton's laws* in terms of comparison.
- Using ingeniously simple original arguments of the greatest physicists and mathematicians of all times: (1) Newton's argument from his celebrated Mathematical Principles of Natural Philosophy (1687) and (2) Euler's argument from his pioneering work on the variational calculus The method of finding curved lines enjoying properties of maximum or minimum (1744). As result we will not need advanced mathematics (all arguments require only high school algebra such as expressions $(a \pm b)^2$ and basic properties of parabola). Moreover we also obtain an excellent foundation for computer modeling, which is important in getting good intuition and experience.

So how does classical mechanics explain the motion of a falling apple? We will show three different approaches – tools for answering this question: *Newton's laws*, *Hamilton's* and *Maupertuis'* principle of least action. As we will see below, together they form a simple toolkit of mechanics in which the question being asked about any system determines directly which tool should be used to predict the motion of that system.

Motion of a falling apple from different points of views

Newton's laws of motion

We start with the well-known Newton's laws of motion, which are already taught at high schools. Firstly Newton says: "Give me the initial state of the apple, which means the initial position and velocity of the apple".

However giving the initial velocity and position means experimentally measuring two nearby positions at very close instants. In this case the initial (and indeed any) velocity is graphically nothing else than the slope of the *position vs. time graph*, or in the language of spacetime physics the slope of the apple's *worldline*.

Then Newton offers us his laws of motion and answers the questions: *What happens next with the apple? That is, what is the position of the apple at the next instant, if there is Earth's gravity or in general some force F (see fig.1)?*



Figure 1. Newton's laws answer the question what is the position of the apple at the next instant, if we know the initial velocity and position or in other words, we know two very nearby positions of the apple.

If there were no acting force, then according to the first law of motion, the principle of inertia, the apple would continue in motion at the same velocity, so graphically it would follow a straight-line worldline (see fig.2). Instead Earth's gravity (or generally some force *F*) causes a component of motion in the direction of the applied force, as described by the second law of motion, the momentum principle $m\Delta v = F\Delta t$. Competition between these two tendencies results in the parallelogram of which the diagonal represents the worldline of the actual motion (fig.2).



Figure 2. According to Newton's laws the motion of the apple is produced by two "effects": the apple's inertial motion at constant velocity, if no forces act upon it and the motion due to an acting force F. The net motion is then given by the diagonal of the parallelogram of the separate motions that would have occurred.

This process of constructing worldlines (which is conceptually the same for trajectories) is simple, repetitive and universally applicable, so it provides a first-rate foundation for computer modeling. Since today's computers are very fast there is really no need for fancy algorithms in introductory physics teaching. To get a better approximation to the actual motion we simply take smaller time steps.

This numerical method appears in some classics physics texts notably in Chapter 9 in Vol.1 of Feynman's lectures on physics (1964). But it is also very effectively applied in the modern introductory physics curriculum, e.g. in *Modern Mechanics* of Chabay and Sherwood (2002) or in *Unit N* of Moore's Six Ideas That Shaped Physics (2003).

Hamilton's principle of least action

Now we apply a first action model to our falling apple based on energy concepts and Hamilton's least action principle. Hamilton tells us: "Give me both initial and final positions and times of the apple," called in spacetime physics *events*. If we specify the initial and final events in advance, then Hamilton's principle can successfully answer the following question: *What is the middle event for the apple? Or which worldline is followed by the falling apple between the initial and final events, if the apple has potential energy U(x) (see fig.3)?*



Figure 3. Hamilton's principle answers the question what is the middle position or more generally the middle event for the apple, if we know the apple's initial and final events.

Now what special property does the actual worldline obey? The principle of least action discovered by Hamilton says that the apple follows *the worldline for which the average kinetic energy minus the average potential energy is as little as possible* or put more briefly worldline has *the least action*, because Hamilton's action *S* is defined as

 $S \equiv \begin{pmatrix} \text{difference between} \\ \text{averagekinetic and potential} \\ \text{energy along the worldine} \end{pmatrix} \cdot \begin{pmatrix} \text{time duration} \\ \text{of motion} \end{pmatrix} \text{ or }$

$$S = \left(\left\langle K \right\rangle - \left\langle U \right\rangle \right) \cdot \left(t_{final} - t_{initial} \right) \quad (1)$$

Using integral calculus the definition (1) has the form

$$S = \int_{t_{initial}}^{t_{final}} (K - U)dt = \int_{t_{initial}}^{t_{final}} Ldt, \qquad (2)$$

where the difference K - U is called the *Lagrangian L*, the quantity that appears in Lagrange's equations of motion.

In the case of our falling apple (and also in general case for small Δt) it is easy to calculate all terms in the expression (1) for action *S* along any worldline 012 (fig. 3). The time duration $t_{final} - t_{initial}$ equals $2\Delta t$. The average kinetic energy $\langle K \rangle$ is given by $(K_A + K_B)/2$, the average of kinetic energies for the first and second segment of the worldline, that is, by $(1/2)(mv_A^2/2 + mv_B^2/2)$, where $v_A = (x_1 - x_0)/\Delta t$ and $v_B = (x_2 - x_1)/\Delta t$.

We now have to pay attention to the potential energy U(x). The shortness of Δt allows us to approximate U(x) by a linear function Cx in the region near point 1. (An additive constant is not important, because it is always zero after an appropriate choice of a reference point.) For the apple constant C is positive and equals mg. Generally we will consider it here as some positive constant. From the viewpoint of the force concept used previously in Newtonian analysis it represents a force F = - $\Delta U/\Delta x = -C\Delta x/\Delta x = -C$, a force in the downward direction. Then $\langle U \rangle$ equals $(U_A + U_B)/2 = (1/2)[C(x_0 + x_1)/2 + C(x_1 + x_2)/2]$. Since the events 0 and 2 are fixed and only position of the middle event 1 is variable, the apple's action S must be only a function of x_1 , in which case it is a quadratic function.

To find a worldline with the least action therefore means that we must vary and find a position x_1 which makes the action a minimum. There are two natural ways to do this. One is the trial-and-error method, perfectly suited for a computer which can quickly calculate and compare the action (1) for millions of worldlines. The detailed description of computer modeling based on the so-called Euler variational method is described in our symposium contributions *Action on Stage* (see fig. 1, 2) and *Use, Abuse, and Unjustified Neglect of the Action principle* (see fig. 1).

The second way to find the least action worldline is the use of mathematical methods. According to Hamilton's principle the action has to become larger, if we change the position x_1 of the middle event 1 of the actual worldline by any small displacement δx . Using only high school algebra one can obtain the following expression for the corresponding change in action:

$$\delta S = S(x_1 + \delta x) - S(x_1) = (m\Delta v - F\Delta t)\delta x + 2\frac{m}{\Delta t}(\delta x)^2$$
(3)

Mathematically equation (3) represents a simple quadratic function with respect to δx whose graph is a parabola. The graphical method proves that the least-action worldline is identical with the worldline predicted by Newton's laws (fig. 4). The method gives students an intuitive and visual understanding of the meaning of the least action principle, as does the computer modeling described earlier.



Figure 4. Both parts of the figure display changes in action with respect to displacement δx . In the left part the linear term in eq. (3) is not zero, i.e. $m\Delta v - F\Delta t \neq 0$. The action demonstrates both negative and positive changes, so the chosen worldline does not yield a minimal action. In the right part the condition that the linear term be zero, $m\Delta v - F\Delta t = 0$, gives a required minimum.

Maupertuis' principle of least action

Finally we will analyze the apple's motion from the viewpoint of the second least action principle called Maupertuis' principle of least action. Maupertuis requires: "Consider a conservative system. Give initial and final position and total energy of the system."

The total energy and its conservation (we again assume knowledge of the potential energy), lead to knowing the apple's initial speed, which implies two possibilities of motion – with the upward or downward direction. But in the case of the falling apple we are interested only in the downward motion. Then according to Maupertuis we are able to answer the question: "What is the apple's final event, if we know its initial and final positions (see fig. 5)?"



Figure 5. The Maupertuis action principle can answer the question "What is the apple's final event, if we know its initial and final positions?"

Since we consider a conservative system the actual motion of the apple must satisfy energy conservation. From Newtonian mechanics we know that it is the same motion as predicted by Newton's laws. Everything seems to be good. So the natural question arises: where is the action principle? But we now see that we did not realize that energy conservation alone actually allows other worldlines, strange and unrealistic with respect to Newton's laws. One example is shown in fig. 6. How to recognize a motion as actual or unrealistic?

The criterion is just the Maupertuis action. It can be shown in a very similar way as in Hanc et al. 2005 that a useful graphical tool in the case is the velocity vs. position diagram called in mechanics *the phase diagram*, which says that for unrealistic worldlines the area under *the phase curve* is always bigger than for the actual one. This geometric idea provides a foundation for the definition of the second version of action, Maupertuis action *W*:

 $W = \begin{pmatrix} \text{area under} \\ \text{phase curve} \end{pmatrix} \cdot \begin{pmatrix} \text{object's} \\ \text{mass} \end{pmatrix} \quad \text{or} \quad W = \int_{\substack{\text{position} \\ \text{position}}}^{\text{final}} mv \, ds \quad (4)$

Summarizing we can say that Maupertuis' principle of least action tells the falling apple to move so that the product of mass and area under the phase curve has the smallest possible value (subject to energy conservation). So far as computer modeling is concerned, it is the problem as before.

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Figure 6. Both depicted worldlines 010 and 010'1'2' satisfy energy conservation, but only one describes the real motion.

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Use, Abuse, and Unjustified Neglect of the Action Principle

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Abstract

Traditionally, differential equations dominated physics education; the action principle was used primarily to derive differential equations such as Lagrange's equations. Now the computer allows the action principle to be applied directly from first principles, often bypassing analytic solutions entirely. The action principle can illuminate and unify physics education and physics research from quantum field theory to cosmology.

Computer solutions without solving equations

In classical mechanics it is not true that action along a particle worldline is always minimum. Often it is a minimum, and it is never a maximum. But sometimes action can be a saddle point, which means that, compared with the true worldline, some adjacent curves have a greater value of the action, while some have a smaller value of the action. Seems complicated. However, it is always true that the action along a sufficiently short worldline -- or a sufficiently short segment of a worldline -- is always a minimum. Therefore we can correctly say:

A particle follows a worldline such that the action along every small segment is a minimum compared with that along every nearby segment with the same endpoints.

Looking at this universal principle tells you immediately that computers are perfect for applying action. Computers do increments beautifully. If a computer finds, by whatever means, a worldline along every segment of which action is a minimum, then that is a true worldline, one that a particle can follow.

Figure 1 shows a frame of an interactive program by Slavomir Tuleja (2005). The goal is to transfer a probe in an unpowered trajectory from a parking orbit around earth to a parking orbit around the moon. We use Hamilton's action *S* because the fixed initial and final points must be events; the probe must get to the location of the moon *when the moon is there*. The dots along the trajectory are ticks on the clock carried by the probe, so the representation completely determines the worldline: position vs time. The operator can drag the clock ticks back and forth one at a time to minimize the total action, can add many intermediate ticks to increase the accuracy, and can ask the computer to minimize the action automatically, which it does in a split second. Notice that this analysis moves directly from the action principle to a visualized solution with no



Figure 1. Transfer trajectory between parking orbits around earth and moon. Dots on the trajectory are the events of clock ticks that completely determine the worldline. The operator can add intermediate clock ticks, drag individual ticks to minimize the action, or have the computer minimize action automatically.

intermediate mathematical analysis. And automatically generated spread sheet data, the time and location of every clock tick, can be analyzed to any desired level of detail.

A critic might object that the solution is now too easy; all the student does is push a few buttons. On the contrary, the student has now been freed to investigate a hugely expanded world of possible problems. For example, by changing the time lapse between initial and final events, the student can search for the worldline that minimizes the total rocket impulse required for the transfer from earth orbit to moon orbit. She can try the same for different parking orbits around earth and moon. She can apply a similar program to transfers between earth and mars. The software offers analysis of motion in other potentials as well.

The action principle for special and general relativity and the cosmos When I was editor of the *American Journal of Physics*, I despaired about the twin paradox, which seemed to poison the literature. Every month some engineer or retired doctor would submit a paper disproving the obviously ridiculous predictions of the twin paradox, thus invalidating special relativity.

In fact the twin paradox is central to the use of action to describe high speed motion: In flat spacetime a true particle worldline yields the longest proper time (wristwatch time, aging) between fixed initial and final events. A general expression for the action uses the Lagrangian L, which for low speeds is the difference between the kinetic and potential energies. $S \equiv \int L dt$

A particle moving at any speed in an electromagnetic field has the Lagrangian

$$L = \frac{1}{2}m\mathbf{V} \bullet \mathbf{V} - \frac{q}{c}\mathbf{V} \bullet \mathbf{A}$$

where ϕ is the scalar potential and **A** is the vector potential. Two equations determine all possible worldlines under electromagnetic influence in flat spacetime!

Now, general relativity is weird, but has the following gorgeous simplification: When there are no singularities or gravitational waves, then at every event on a particle worldline you can always find a local inertial frame in which special relativity holds. Since the worldline is the sum of segments in these local frames, and since proper time is an invariant, the same for all observers, therefore in general relativity the worldline of a particle between fixed end events is the one with maximum aging along each small segment. We call this result *the principle of maximal aging*. For low speeds and small curvature of spacetime, the principle of maximal aging reduces to the principle of least action.

How do we find the value $d\tau$ of the proper time (aging) along a segment of a worldline in curved spacetime? From the *metric*, the solution to the field equations. On the left of the metric equation is the increment $d\tau$ of proper time (wristwatch time, aging) between a nearby pair of events on the worldline. On the right side of the metric equation are the corresponding increments of the (arbitrarily chosen) coordinates between that pair of events.

Now, the metric is expressed in increments; manipulating the metric requires only calculus. This means that if, instead of starting with the field equation, we start with the metric solutions, we can introduce general relativity to sophomores using only calculus and the principle of maximal aging. John Archibald Wheeler and I did this in our text *Exploring Black Holes, Introduction to General Relativity*, Fig. 2 (Taylor & Wheeler 2000)



Figure 2. Text Exploring Black Holes by Edwin F. Taylor and John Archibald Wheeler that introduces general relativity to sophomores using the metric and the principle of maximal aging.

The action principle not only tracks particles in curved spacetime. It is also at the root of Einstein's field equations themselves. Hilbert derived the field equations from an action principle, some say before Einstein completed his theory. Landau and Lifshitz do the same for advanced physics students. Thus one can say that action describes the fundamental non-quantum laws of the cosmos.

Quantum mechanics from the bottom

Recall Feynman's formulation of nonrelativistic quantum mechanics, exemplified by the electron:

• The electron explores all possible worldlines between fixed end events that we choose.

• Along each trial worldline the total rotation of the quantum phasor is S/h = (Action)/h.

• At the end event, add up phasors for all worldlines to give the resultant quantum amplitude.

• The probability of detecting the electron at the final event is proportional to the squared magnitude of the resultant quantum amplitude.

This is not a new idea! Sixty four years ago it was summarized in the introduction to Feynman's 1942 Ph.D. thesis under John Wheeler: *A*

generalization of quantum mechanics is given in which the central mathematical concept is the analogue of the action in classical mechanics ... It is only required that some form of least action principle be available ... if a Lagrangian exists ... the generalization reduces to the usual form of quantum mechanics. In the classical limit, the quantum equations go over into the corresponding classical ones, with the same action function. (Brown 2003)

Feynman was a co-recipient of a Nobel Prize for expanding these ideas to quantum field theory, which one can take to be the most fundamental current theory of the very small (a status that string theory has not yet achieved). And quantum field theories can be derived from action. A quote from the Web: "Of all possible fields with a given boundary condition the one that provides an extremum . . . of the action is The Solution."

Thus action carries us seamlessly from the smallest that we know to the largest, the universe as a whole.

Variational principles: parents of action

... once the laws of physical theory are expressed as differential equations, the possibility of their reduction to a variational principle is evident from purely mathematical reasoning ... (Yourgrau & Mandelstam 1968)

Traditionally differential equations have been the analytic tool of choice in physics, both for education and research. As we have seen, the computer can apply variational principles directly, often eliminating intermediate mathematical analysis. The use of variational principles in current physics text is, at best, spotty. A few scattered examples:

Landau and Lifschitz develop the first two Maxwell Equations from experiment and hand-waving. The last two equations they derive from a variational principle, which they call action.

A standard method for finding the ground state wave function of an atom is to minimize the electromagnetic energy.

The relaxation method is a powerful one for determining the electrostatic field resulting from an array of fixed charges.

Textbooks often miss powerful and simplifying applications of variational principles. For example, Van Baak (1999) replaces Kirchoff's circuit theorems by requirements that (1) current is conserved, and (2) the rate of dissipation of energy is minimized. By using this method, he says, the usual "extravagance of equations is wholly avoided."

Strategies for introducing action

Variational principles -- and action -- are tools, like differential equations, and not fundamental physical principles (though they are related to conservation laws through Noether's theorem; see e.g. Hanc et al. 2004). Still, they are unifying tools that the computer can implement throughout physics education and research. Here are some notes on strategies for introducing them to physics instruction:

1. Sneak bits of action and variational principles into secondary classes and introductory undergraduate courses (see particular examples in Hanc et al. 2003 or Hanc & Taylor 2004).

2. Do NOT make action the primary tool in introductory physics; it is not concrete enough. Introductory students need to feel the pushes and pulls of forces.

3. Use action and variational principles as unifying tools in the remainder of undergraduate and graduate programs.

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Software and background publications are available at www.eftaylor.com/leastaction.html;

Paper sessions

Modeling in Physics Education

Modeling in Non-linear Physics

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Abstract

In the study of complex dynamical systems, topics as chaos, fractal analysis, self organized criticality (SOC), non-stationary time series analysis, and others are emergent. Non-linear dynamics is a new way of applying the known laws of Physics, with the aid of the computer, to many phenomena that encompass, in addition to the traditional in Physics, phenomena of Biological and Social Sciences. In this work, we review some models that have been important to understand many concepts of non-linear dynamics, as the sand pile model to understand SOC concepts: By using this basic model we can study forest fire models, epidemic models or we can build spring-block models to mimic the dynamics of a seismic fault. We also review some models applicable to Physiology. For the study of these and many other models the student needs University Physics, besides he needs to know the system basics that he is studying (for example, the basics of the heart Physiology if he is working with models of the heart dynamics) and he also needs the computer. We can teach to the student basic models and later he can do modifications to model new situations, very often these applications are very illustrative and interesting. These topics have not been approached in the university Physics courses and its study has been postponed to the graduate courses, we propose to include them in the undergraduate Physics curriculum. The undergraduate student has all the elements to work with success many of these non-linear basic models

Introduction

Some decades ago we only studied phenomena that obeyed integral equations, in particular the linear ones. If a non-linear phenomenon was studied it was transformed by means of a linear approach. It seemed that in Nature the really important thing was the family of linear phenomena and that the other ones were an exception, they were undesirable for the difficulty of their treatment. It seems that now it begins to be accepted that the immense majority of the natural phenomena are not linear, and that the other ones are the exception.

Non-linear dynamics

Many concepts of the non-linear dynamics have arisen, some of which surely are known by the students, for instance: Power laws in Physics, Physiology and other areas; random walks in the stock market and under the microscope; floods, forest fires, galaxies distribution, and other cases with statistical auto-similarity. Cantor and Julia's sets have been popularized in the Internet and the term "art fractal" has been coined. In fact, fractals and their characterization using fractional dimensions are now very popular.

Chaos

In the moment of its discovery, the phenomenon of chaotic movement was considered a mathematical rarity. In 1963, Edward Lorenz had a mathematical basic program to study a simplified model of the climate. Since the code of the computer was deterministic, Lorenz thought that introducing the same initial values, he would get the same result when executing the program several times. Lorenz was surprised because drastically different results were obtained every time. For the limitations of his equipment, lightly different values were introduced. This principle sometimes is called the "Butterfly Effect".

Non-linear dynamics and complexity

Non linear-dynamics is a new and promissory way to apply the wellknown laws of Physics, with the fundamental help of computers, to very varied phenomena that embrace, besides the traditional ones in Physics, those that show up in the Biological Sciences and the Social Sciences. Complexity designates the study of dynamic systems that are in some intermediate point among the order and total disorder. These systems become extremely sensitive to their initial conditions. One of the more interesting results due to the emergence of this new research field is that they have formed interdisciplinary research groups to study the inherent problems of dynamic complex systems. Complexity of a system should not be confused the fact that a system is complicated. In fact, we should speak of complex behavior of a system, because a dynamic system can be very simple but it can exhibit under certain conditions an unexpected behavior of very complex characteristics.

Some applications and models

There are applications of the non-linear dynamics to Physics, Chemistry, Biochemistry, etc. Many topics of non-linear dynamics are important research themes of the scientific community, some of them have been successful in explaining complex behaviors observed in nature, some of them have had only partial success. Among the last, it can be mentioned the self-organized criticality (SOC) that tried to explain some ubiquitous patterns that exist in the nature, among them fractal structures and catastrophic events. According to Per Bak [1], SOC can explain massive extinctions. The concept was proposed in 1987, the basic idea is simple and most of the mathematical models that have been used in the implementation of the theory are not complicated. Almost anyone that knows basic programming and with a PC can implement the models to verify their predictions. Another concept that has been mentioned much lately is the one that refers to multifractal analysis [2, 3, 4]. Although at the beginning multifractals were perceived as an isolated surrounded

island regulated by an occult formalism, lately there have been important advances in the popularization of the related concepts and the multifractal analysis has been constituted as a very useful tool in the analysis of certain type of time series. They have been identified in different fields in independent form and they have been named in different ways. In Physics and Engineering this phenomenon is called 1/f noise. Others talk of non-Fickean Diffusion. The turbulence specialists associate some instances of the phenomenon with intermittence.

Time series analysis

The most direct league between chaos theory and the real world is the analysis of time series of real systems in terms of non-linear dynamics. Traditionally, stochastic linear processes have modeled the non-periodic signals. But inclusive the dynamic simplest systems can exhibit temporary strongly irregular evolution. Chaos theory offers new concepts and algorithms for the study of time series that can take to a better understanding of signals. There are new concepts and methods as the Lyapunov exponents, noise reduction, non-linear prediction, dimensions and entropies as well as statistical tests for the nonlinearity. Others are control chaos, wavelet analysis and pattern dynamics [5, 6]. The theory of non-linear dynamical systems provides new tools and quantities for the data characterization of irregular time series. The analysis of time series has physiologic important applications, for example, starting from the analysis of interbeat heart time series [3, 4] some heart anomalies can be recognized.

An example, modeling the dynamics of a seismic fault.

The theory of plate tectonics says that the lithosphere is broken into about a dozen major rigid plates and several minor ones. These plates slowly grind against each other, building up stress and creating faults. Seismologists have observed that small quakes occur more frequently than large quakes. Gutenberg and Richter established a scaling relation between the magnitude and the frequency of earthquakes. The Gutenberg and Richter relation is $log_{10}N(m) = a - bm$, where *a* and *b* are constants and N(m) is the number of earthquakes greater than *m* in a specified time interval [7, 8]. A first check on the robustness of an earthquake-fault model is that it be able to produce these scaling relations. However, the ability to produce a scaling relation does not mean that the model is useful, because it also must be able to reproduce other known phenomena and led to predictions that the seismologists can observe on real faults.

Seismic faults models

The Olami, Feder and Christensen (OFC) model was proposed in 1992 [7]. The OFC model is a non-conservative cellular automaton model for describing the dynamics of a 2-D array of rigid blocks on a frictional surface (Figure 1). It consists of an *LxL* array of individual blocks identified by (i, j), where i, j are integers between 1 and L. Each block is connected to its four nearest neighbors by springs with elastic constants K_1 and K_2 and it is connected on its top to a moving driving plate by means of a spring with stiffness K_L . The displacement of each block from its relaxed position on the lattice is $X_{i,j}$ and the total force exerted by the springs on a block (i, j) is given by [7]

$$F_{i,j} = K_1 \Big[2x_{i,j} - x_{i-1,j} - x_{i+1,j} \Big] + K_2 \Big[2x_{i,j} - x_{i,j-1} - x_{i,j+1} \Big] + K_L x_{i,j}$$

When the two rigid plates move relatively among them the total force in each block it is increased uniformly (with a rate proportional to $K_L V$, where V is the relative speed among the plates), until a site reaches a value limit and the relaxation process begins). The redistribution of forces after local slip at position (*i*, *j*) due to the force on one of the blocks is larger than the maximal static friction and is given by

$$\begin{split} F_{i\pm 1,j} &\to F_{i\pm 1,j} + \delta F_{i\pm 1,j} \\ F_{i,j\pm 1} &\to F_{i,j\pm 1} + \delta F_{i,j\pm 1} \\ F_{i,j} &\to 0 \end{split}$$

where the increments in the force on the nearest-neighbor block are

$$\begin{split} \delta F_{i\pm 1,j} &= \frac{K_1}{2K_1 + 2K_2 + K_L} \, F_{i,j} = \gamma_1 F_{i,j}, \\ \delta F_{i,j\pm 1} &= \frac{K_2}{2K_1 + 2K_2 + K_L} \, F_{i,j} = \gamma_2 F_{i,j}, \end{split}$$

 γ_1 and γ_2 are called the elastic ratios, and for the case $K_L > 0$ the redistribution of the force is non-conservative, as is expected to occur in actual earthquakes. This redistribution redefines the forces in the nearestneighbor blocks, and further slips can occur, causing a chain reaction (synthetic earthquake). For instance, in Figure 2, we show the surface rupture that constitutes a synthetic earthquake. We can count the relaxed sites so we can assign a magnitude to each earthquake, as it can be seen in Figure 3, we can repeat a lot of times the same procedure, therefore we have many events with different magnitudes, all of them form a time series of magnitudes (Figure 3). We can see that these synthetic earthquakes follow the Gutenberg-Richter law (Figure 4). This model and other modifications of the same model can reproduce qualitatively many features of real seismicity [8].



Figure 1. The geometry of the spring-block model. The force on the blocks increases uniformly as a response to the relative movement of the two plates.



Figure 2. The rupture surface in a synthetic earthquake. The X point is the epicenter



Figure 3. Time series of synthetic earthquakes (16384 events).



Figure 4. Gutenberg-Richter law for synthetic earthquakes.

Conclusions

The field is prepared to intend that subjects of non-linear dynamics are included in Physics undergraduate programs, there is already a lot of materials that can be used to make an effective approach to such topics at university level besides that there exist many divulgation materials. Including these topics would open the students a panorama to one of the Physics areas that has been advancing a lot in the last times. But the applications that are carried out are also intrinsically very interesting and now the theory has become accessible more than ever, so this proposal of including new courses can also extend to the Engineering careers, mainly those that have to do with physiologic systems, for example, we can intend a course of time series analysis for the biomedical engineers that have to analyze time series of multitude of physiological signals, most of which it has been shown that exhibit non-linear behavior.

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A Methodology to Study Students' Explanatory Models for Buoyant Force: Spiraled Exploratory Inquiry and Hypotheses Testing

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Abstract

This paper reports a novel experimental design that was developed to carry out an inquiry about explanatory models that university students have about buoyant force. This experimental design involved two stages: a spiraled exploratory inquiry and the testing of the working hypothesis. The first stage consisted of a series of steps that are successive approximations towards the identification of the students' models. These steps are: a preliminary design of a potentially adequate inquiry instrument, the collection and analysis of data (students' answers), and the ordering of the given explanations on the base of "answer categories" that were defined and coded. These steps allow the detection of characteristic configurations given by the simultaneous presence of certain categories. These configurations were named "category groupings" and were taken as indicators of the existence of explanatory models. With these results, the preliminary inquiry instrument was improved in order to refine the categories that were detected in the first step. Then new data collection was carried out three times, following the same set of steps. The hypothesis testing stage was planned taking into account these results. This research made use of qualitative and quantitative techniques. In all cases, the instruments' validity was checked. As a result of this research, a set of explanatory models about buoyant force that students study when dealing with bodies submerged in liquids, was proposed. The degree to which these models are shared by students was quantified. A selective activation of different explanatory models was identified, depending on the problem situation at hand.

Introduction

This paper reports the experimental design adopted for the development of an inquiry of university students' explanatory models for buoyant forces. The working hypotheses were:

H1: Faced with problem-solving situations that involve submerged bodies, students use explanatory models about buoyant force.

H2: There are groups of students who share the same explanatory model.

H3: Students may have different coexisting explanatory models and use one or another depending on the context of the problem situation at hand. An experimental design for the detection of students' explanatory models - taking into account the point of view we proposed at the beginning of this inquiry - was not found within the bibliographic search (Cohen & Manion, 1996; Creswell, 1998). Previous works had already described some naive conceptions that students have about this topic (Fernandez, Jardón, Laura & Utges, 1993; Flores Camacho & Gallegos Casares, 1998). The purpose of this work was to detect the variables that students considered relevant to explain the buoyant force and the relationships they established between those variables. Because different students used different intuitive conceptions, we expected that different students adopted different variables and relationships to explain buoyant force. In a first stage, we designed an exploratory inquiry which allowed us to detect explanatory models. In a second stage the hypotheses testing was carried out on the basis of the explanatory models found.

Methods

The experimental design was planned in steps: "spiraled exploratory inquiry" and "hypotheses testing". A combination of qualitative and quantitative techniques was used during the research. During both steps statistical analysis were made whenever they were considered relevant (for example, to define the selected population of students needed to testing the three hypotheses put forward) (Siegel, S., 1970).

Spiraled Exploratory Inquiry

During the spiraled exploratory inquiry successive approaches were made, through the following activities:

- Design of research instruments potentially adequate for the inquiry.
- Data collection and report of students' answers to questions related to buoyant forces.
- Classification of the elicited explanations, defining and coding "answers categories" according to answers based on any characteristic considered relevant by students (For example, "Buoyant force depends on the amount of liquid in the container", codified C5).
- Analysis of the way in which students made use of different categories, and detecting patterns, named "category groupings" (For example, some students only used categories codified A1 and C3). These category groupings were considered as possible indicators of explanatory models.
- Reformulation of tools and new data collection.
- New revision of the relevancy of the categorizations and of their groupings depending on the new information.

This whole process involved the elaboration of three questionnaires and a semi-structured protocol interview.

Questionnaires – for individual and written answers - and interviews were used for collecting data. Questionnaires make possible to obtain answers from large groups of students. Interviews provide a deeper insight into students' concepts and forms of reasoning. Incidental samplings were selected for the questionnaires. Reputed cases were selected for the interviews.

An incidental sample (Sirvent, 1997) does not have the characteristics of statistical sampling. In this research, the groups where made up of students who, besides taking a certain university course during a certain academic year, attended classes on the day in which the questionnaire was administrated. Individuals chosen by their reputation are referred to as reputed cases (Sirvent, 1997). In this research, they were students with high academic performance.

In every case, both for questionnaires and for interview protocols, the study of instrument validity was conducted through their consideration by external judges and the development of pilot experiences (answers elicited from small groups of students). This made possible to control the clarity of the answers and their relevance for the research objectives. In each case, definitive versions were written down following the modifications resulting from both instances.

For the control of instrument reliability, they included more than one question pointing to a same aspect.

Questionnaire 1 was administered to Group 1 (students from different degree programs in UNSa -National University of Salta, Argentina-). The group included two sub-groups with different characteristics:

- Group "pre": Students who had not had formal university instruction on the subject "buoyant force" (freshmen), N = 78.
- Group "post": Students who had already studied the subject "buoyant force" (students taking the Physics II course and who had studied Hydrostatics in the previous semester), N = 25.

Questionnaire 2 was administered to a team of students labeled Group 2, made up of five groups of students from different university courses, all of them with formal instruction on Hydrostatics:

- Group Ex: Chemistry students (Licentiate and Teacher Training courses), UNSa. (N=12).
- Group Geo: Geology students, UNSa. (N=11).
- Group Nat: Agronomical Engineering students, UNSa. (N=26).
- Group Ing1: Engineering students (Civil, Chemical and Industrial), UNSa. (N=13).
- Group Ing2: Civil Engineering students, UNT (National University of Tucumán, Argentina). (N=18).

Semi-structured interviews were administered to a small number of students with the aim of obtaining more complete verbal explanations to be analyzed. The protocol of a semi-structured interview and some simple experimental devices (necessary for the implementation of the interviews) were designed. During the interview students were faced with concrete experimental situations related to submerged bodies, and they were required to make predictions and give explanations on the behavior of the bodies involved. The interviews were given to students selected as reputed cases, all of them having formal instruction on Hydrostatics and high academic performance (all of them from UNSa).

The predictions and the explanations elicited showed some severe misunderstandings, even though they came from students with a high academic performance. These misunderstandings were mainly related to the volume displaced by the body, to the distinction between weight and apparent weight, and to the variables related to the buoyant force. After a reflective analysis of the behavior of simple experimental systems, students who initially gave conceptually incorrect answers were able to clarify the concepts involved.

Questionnaire 3 was designed to develop the Pilot Experience of Hypotheses Testing. It was aimed both at inquiring about explanatory models on buoyant force already identified, and at exploring the existence of other possible students' explanatory models. In this stage, a decision had been taken to restrict the administration of the questionnaire to students from UNSa, as a result of a statistical analysis. Thus, questionnaire 3 was administered to a group of students (who had already studied the subject "buoyant force") referred to as Group 3 (N=103).

When the previous stages were finished, we had a preliminary set of categories and explanatory models proposed.

Hypotheses testing

The stage of Hypotheses Testing was planned on the basis of the results obtained from the Pilot Experience. A new tool was designed. Questionnaire 4 was administered to Group 4, made up of 97 students from different degree programs in UNSa, who had already studied the topic Hydrostatics. A statistical analysis showed that no meaningful differences could be detected between Group 4 and Group 3. In another paper (Alurralde & Salinas, 2006) a discussion is presented of the results obtained during the development of the research.

Results

Table 1 resumes the results in relation to the categories of answers. The final listing of answer categories which were used for the hypotheses testing is shown.

Al	The buoyant force depends on the volume of liquid displaced.
B1	The buoyant force depends on the weight/mass of the body.
B2	The buoyant force depends on the density of the body.
B3	The buoyant force depends on the volume of the body.
C1	The buoyant force increases when depth increases.
C2	The buoyant force depends on pressure.
C3	The buoyant force depends on the density of the liquid.
C4	Student does not discriminate buoyant force/pressure.
D	The buoyant force depends on the horizontal surface of body-liquid contact.
E1	In the presence of other forces student does not know how to explain the buoyant force.
E2	The buoyant force does not act or is less when the body is in equilibrium.
E3	The buoyant force depends on the connections.
Gl	The buoyant force is greater if the body is higher (degrees of floatability).
N۸	Non-usable answers

Table 1. Answer categories

From the final categories listing shown in Table 1, students' arguments were revised. Through this analysis, explanatory models shown in Table 2 were proposed.

Scientific Model: comprised by answers consistent with the scientifically accepted model. Those students who seem to committed to Scientific Model exclusively use answer categories A1 and C3.

Model 1: The variables considered relevant for buoyant force are those linked exclusively to the submerged body (mass, weight, density, volume). Those students who seem to adhere to Model 1 use answer categories B, but do not use answer categories C (except for C3 which might be used on certain occasions).

Model 2: The variables considered relevant for buoyant force are linked only to the fluid (pressure, depth). The students who seem to adhere to Model 2 use answer categories C, but do not use answer categories B.

Model 3: The higher the body is in the liquid, the stronger the buoyant force is (at lower depth). This model seems to define a "flotation degree" for bodies, associating a stronger buoyant force to bodies that are closer to the surface.

Table 2. Explanatory models proposed

The set or explanatory models described above was proposed as an interpretation of the category groupings present in students' answers. Groups were found of students who shared these grouping and that, consequently, seemed to share the adhesion to the associated models.

From the analysis of students' answers that showed category groupings which didn't seem to fit in any of the defined models, new evidences appeared to show that, in physically equivalent situations, students gave different explanations in terms of some particular condition present in the problematic situation put forward. These explanations were characterized as category groupings Type QA (Pairs question-answer), as shown in Table 3.

Conclusion

The working methodology of this inquiry was not a conventional one. Some naive students' conceptions were known (Alurralde & Salinas, 1999), and they were similar to the ones detected by other authors (Fernández et al. 1993; Flores Camacho & Gallegos Casares, 1998).

Туре	Alternati	ve explanations
QA	For bodies partially submerged, they	For bodies completely submerged, they
	adhere to Model 1	adhere to Model 2
QA1	In the absence of connections, they adhere to Model 2.	In the presence of connections, the buoyant force depends on the connections.
QA2	In the absence of connections, they adhere to the model accepted scientifically	In the presence of connections, the buoyant force depends on the connections.

Table 3. Students' Q-A Type responses

Following the orientation of those results and of teaching experience on the subject, an inquiry was designed. It did not look explicitly for predetermined conceptions, but it put forward problematic situations which made possible the detection of the variables which students considered relevant for buoyant force. Then, also in an open way, without limiting the inquiry to the finding of predetermined particular structures, characteristic answer grouping were searched for. They were taken as indicators and through them it was possible to propose explanatory models as an interpretation of students' answers. This process was developed in successive steps, and the results obtained from data collection were revised in several occasions. Each new category of answer or each new characteristic grouping demanded a new revision of questionnaires and transcriptions of interviews in the light of the new information. That is the reason why the stage previous to the hypotheses testing has been characterized a "spiraled exploratory inquiry".

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Learning with a Virtual Camera – The Use of Multiple Representations for Learning

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Abstract

Multicoding, i. e. using various kinds of representations, can foster flexible thinking. Especially offering different visuals can bridge the gap between theory and practice.

With this intention we developed a virtual camera, using multimedia to uncover basic physics of photography. A user can switch between a realistic view of a camera and a model, showing the physical components (lenses, aperture, image plain) and in particular rays of light. Different objects, including a moving pendulum, can be photographed. Exposure time and aperture have to be set according to the characteristics of an object. Pictures are presented immediately and the results can be understood by examining the model representation. Learning with the virtual camera has been studied empirically with 95 pupils (10th grade) and 35 teacher students. It was looked at learning outcomes in dependence on learners' abilities and the influence of narrowly or not so accurately described exercises. For statistical analysis t-tests and ANOVA were applied.

Results indicate that adjusted guidance is important, depending on learners' abilities, and an intensive and goal-oriented working with the computer program should be assured. Under these circumstances learning outcomes were found to be satisfactory for pupils as well as for students (on a higher level). Nevertheless one single lesson turned out to be too short to learn about complex dependencies and the virtual camera should be integrated into an overall concept.

Details will be outlined in the following sections, focusing on:

* multicoding and cognitive flexibility

* learning contents and the virtual camera as an aid to connect model and reality

* the empirical study and results.

Multicoding, mental models and cognitive flexibility

Multicoding comprises the use of multiple representations for one topic. This facilitates focusing on special aspects in an adequate way, using the strength of specific descriptions or visualizations. Especially various illustrations can bridge the gap between theory and practice (see fig 1 and Girwidz et al. 2006a, b).

Mental models are analogous, pictorial representations, enabling the brain to simulate complex systems and to imagine how they might work under different settings. Classical examples are the functioning of a steam engine or an electric buzzer (De Kleer & Brown 1983). Mental models follow the assumption that human beings construct cognitive models of reality, reflecting aspects that are important for an individual. They provide a reference frame for understanding new issues and offer a base for subsequent planning (Dutke, 1994). Multimedia may combine several types of presentation and thus also avoid overemphasizing superficial aspects by one specific representation.

For problem solving, the use of an adequate representation is important (already underlined by Larkin, 1983). The ability to alter from one representation to another in order to find an appropriate representation is a central aspect of cognitive flexibility.

"Cognitive flexibility" includes the ability to restructure existing knowledge according to the demands of a given situation (Spiro & Jehng, 1990). Thus, a knowledge ensemble can be tailored to the needs of a problem-solving situation, or can support learning and linking of new concepts (Spiro, Feltovich, Jacobson, & Coulson, 1992). Cognitive flexibility helps to apply knowledge under various conditions in an effective way.



Fig. 1: Snap shots from the program "virtual camera", opposing a realistic view and a model.

To reach this, a learning environment is required, that offers corresponding features and possibilities to change from one representation to another.

This was a guide line for designing the "virtual camera", bringing together:

a) objects to be photographed

b) a superficial view of a camera and lifelike operating controls

c) a physical model of a camera with components like lenses, aperture, and rays of light

d) resultant pictures.

Altering between different instrument settings and analyzing corresponding results is made quick and easy. Interrelating settings and results, theory and practice is intended. Beside the use of different representations, active learning is essential to foster applicability and to overcome inert knowledge. Students have to work with the material. This was supported by a workbook, also maintaining goal-directed learning.

Subject matter by examples

How to shoot pictures of moving objects? Can motion be symbolized by fuzzy pictures?

When will background and foreground both be focused sharply? What are adequate settings for aperture and exposure time?



Fig. 2: How to shoot moving objects?



Fig. 3: How to obtain depth of sharpness.

Finding the right answer requires basic knowledge about optics. Furthermore different aspects have to be interrelated (relationships between aperture, exposure time, distance, lighting conditions, movement). A kind of multidimensional problem solving might become necessary, depending on the desired exposure.


Fig. 4: Understanding depth of sharpness.



Fig. 5: Explaining fuzzy / wiggly pictures.

Changing and arranging different views is made easy in this computer application. Cross referencing model and reality is supported. For example, corresponding operating devices are located at the same position and can easily be identified in both representations. The virtual camera can be used or downloaded from the website: http://www.film-phl.de or www.physikonline.net.

A complex subject matter

The topic is also interesting for studies about learning and problem solving, because multiple connections and relations have to be considered (see fig. 6). Thinking can step forward on different abstract levels, can include characteristics of the object, settings of the camera, the physical view and relate them to the photo-optical results.



Fig. 6: Connections between different aspects.

Active learning

In order to support active learning we used workbooks to assign tasks, to pose questions and to present problems which had to be solved. Two kinds of worksheets were developed: one to assist discovery learning, one to arrange a more guided learning. Nevertheless, cognitive and practical activities were impelled in both versions.

The empirical study

How to use the camera in school lessons? Should students use the program self dependently for discovery learning or is guided learning better? Are open tasks adequate for brilliant students and, on the other hand, in-depth defined exercises better for not so gifted students? Does this computer application offer insights only for novices or is it also helpful for more experienced learners?

Sample characteristics and procedure

Participants in this study were 95 tenth graders at junior high school of intermediate abilities (in Germen: Realschule). They were pre-tested, focusing on their knowledge in photography three weeks before the main study. Furthermore, their achievement in physics and chemistry was assessed according to their school marks. The population was divided into two subgroups to compare different workbooks, one for discovery learning, the other one for more guided learning. On the average the students worked 31 minutes with the program and workbook. In addition also a group of 35 teacher students was tested.

Testing

The test contained 12 multiple choice items, leading to a maximum of 12 points. The questionnaire had to match two objectives. First, two levels of complexity should be tested: Questions referring to one modification only (e. g. changing of the aperture) set up the subscale "one-dimensional interrelationships", and questions referring to more complex dependencies (e. g. how to obtain depth of sharpness) belonged to a subscale "complex connections". Second, the questions should refer definitely to one form of representation ("model" or "superficial view") and should indicate whether or not working with this representation was successful. (The questions were pre-tested with students and revised before usage.)

Results referring to different subtopics

Pre- and post-test as well as subscales were compared using t-tests (after checking normal distribution with Kolmogorov-Smirnov-test). Over all, there was a significant improvement (T=6,0; p<0,001). Questions requiring the work with the "model representation" were treated as good as questions that referred to the "realistic view". However the improvement referred more or less exclusively to "one-dimensional

questions". Obviously a more complex understanding requires more time for learning. Table 1 presents an overview.

<i>n</i> = 95	All (max. = 12)		"one-dim. interrelations" (max. = 6)		"complex interrelations (max. = 6)		realistic view (max. = 5)		model representation (max. = 5)	
	М	SD	М	SD	М	SD	М	SD	М	SD
pre-test	3,2	1,8	1,5	1,1	1,8	1,3	1,2	0,9	1,5	1,1
post-test	4,6	2,2	2,8	1,4	1,8	1,2	1,8	1,1	2,1	1,4
difference	1,4	2,3	1,3	1,7	0,1	1,5	0,6	1,4	0,6	1,3
t-value	6,0		7,7		0,6		4,6	<u>.</u>	4,3	
р	< 0,00)1	< 0,00)1	0,52		< 0,0	001	< 0,00	1

Tab. 1: Working with different representations.

Results - Interference between capability and kind of workbook?

A 2x2-desing was applied to detect dependencies between different workbooks and the capability of learners. A median split, based on the school grades, divided students in two groups (strong learners and not so strong learners). An overview over the results is shown in table 2. There was no significant difference between strong and weak learners. Though strong learners did better with discovery learning, an interaction effect (according to ANOVA) was not significant.

<i>n</i> = 95	guided working	discovery learning	both together	
strong learners	n = 23 M = 0,4; SD = 1,8	n = 21 M = 2,2; $SD = 2,1$	n = 44 M = 1,3; $SD = 2,1$	
weak learners	n = 25 M = 1,4; SD = 2,3	n = 26 M = 1,7; $SD = 2,5$	n = 51 M = 1,5; $SD = 2,4$	
all together	n = 48 M = 1,0; SD = 2,1	n = 47 M = 1,9; $SD = 2,3$	n = 95 M = 1,4; $SD = 2,3$	

Tab. 2: Capability and working method.

Our interpretation is that common school grades do not determine absolutely whether guided learning or discovery learning is better for an individual. More factors have to be taken into account, especially some of those that are not included in normal school notes.

Tenth graders and students

The program was helpful for tenth graders but also for university students. Though they started on a higher knowledge level and had better pre-test values, their gains were in the same range (on a higher level). The conclusion is that the program does not only offer material for one single lesson and can be used at various levels.

Outlook

One single lesson turned out to be too short to learn about complex dependencies. The virtual camera should be integrated into an overall concept. Three or four lessons should be available, including discussions, examples from reality and also enclosing real experiments. In order to find out more details about students' working, a new program version with a capture and replay tool will be implemented. So all activities can be logged, replayed and also categorized. Reactions on different hints will be studied.

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Models for Physics Teachers from the World of Pictures and Sounds

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Abstract

The cultural history of physics is an important part of teaching introductory physics for engineering students. This way pictures and sounds can also be part of the course. Paintings and "visible" sounds offer numerous possibilities to help like simple models to understand physical phenomena and laws.

The poster intends to show some examples from the world of pictures and sounds in many topics of physics. We can find some paintings and drawings, which can be models of scientific thinking and modeling itself. Numerous works of painters, who dealt with the relation of light and space, can be thought of as optical study. There are several other topics of physics, which can be reflected in paintings, like the uncertainty principle, concepts of nuclear physics, concepts of the theory of relativity, etc. The analysis of the sounds and making sound visible is also suitable to show many physical concepts – besides the sound wave itself. We can mention superposition, magnetostriction, the uncertainty principle, etc.

Introduction

"If we really want to say anything at all about nature, we must somehow pass from mathematical to everyday language." (N. Bohr)

Visible and audible models can help to realize Bohr's quoted thought. Paintings and the sounds of music and noises offer several possibilities to create associations in order to make physical phenomena or laws more understandable. Using these types of models we can widen the examples and at the same time we can emphasize the fact that we have only one culture (which includes both science and arts).

Using an arbitrary classification, this presentation shows some examples from the world of pictures and sounds as possible models in teaching physics.

Modeling in the mirror of paintings

The teacher, who uses a painting to illustrate a theory, selects one or more elements from the picture which are analogous to components of the theory, and in this way the painting becomes a model of the theory.

Actually we can say that *every painting is a model itself*. The painters create models of different parts of the real world: finally it depends on the observer what he or she sees looking at a painting – instead of colored patterns on a canvas.

What is Jan van Eyck's painting, *The Arnolfini Marriage* modelling? The observer can see the main subject of the painting (the

marriage), or the image formed by the spherical mirror, perhaps the process of forming the image. Sometimes the light and shadows are the main points for the observer, or the illusion of depth, created by light and the size of the things. But we can be sure that the observer of the painting does not see just colored dots of paints.

M.C. Escher's work, *The Waterfall* can easily cause a false idea that it shows a real-life construction. But we can understand the essence of the picture – looking behind the surface, - if we know the impossibility of a waterfall, working like a perpetual mobile and the optical illusion which is applied. The difference between the "surface" and the essential facts is similar to the difference between *interpretations of the motions* given by Aristotle and Galileo. It is the same situation in the *process of modelling*: we have to highlight essential characteristics, which sometimes do not appear for us at the first sight.

Paintings as optical studies

There are several paintings, which can be thought of as optical studies.

M.C. Escher's work, *Three Spheres II* represents well *the reflecting characters of a surface of a sphere*. He shows, at the same time, how various spaces coincide in this mirror effect, where the maker is present at the center. *Observer and creator are not separate* but indivisibly connected.

In Vermeer's painting, *A woman Reading a Letter*, the window *reflects* the young woman's features. A bare wall reflects the light and envelops the woman in its luminosity. Here we also can realize that "…*light not only helps to model the forms of the figures, but is equal in importance to perspective in creating the illusion of depth." (1).*

This way we are confirmed that the *art of perspective* is near to the optics.

From the numerous perspective paintings let us have here only one of the great Dutch landscapes, Hobbema's picture, *The Avenue, Middelharnis,* where the fantastic depth of the painting is also supported by the colors (e.g. we have a feeling that the blue coloring subjects are in the further distance).

Victor Vasarely has several works which we can use to show *the diffraction patterns*.

The title of Dali's work, *The Image Disappears* is able to tell us more than an allusion to the duality of the topic of the picture: the vision of *The Reader* by Vermeer whose outline appears in a second image, in Velasquez's face. The physics teacher can connect the title and the painting to the *dual wave-particle nature of light*. In the picture we can discover sometimes a reading woman, sometimes a face of a man, while they are models, in fact we see colored parts of the canvas. Similarly to light: it can behave like particles, or wave, while it is neither particle, nor wave, but "light". In the Manet's painting *A Bar at the Folies-Bergère*, the real world and a second one in the plane mirror complement each other. Beside the *mirror effect* this painting can be a model of the theory of *complementarity*.

Modern physics reflected in paintings

The idea of *four-dimensional space-time*, turned up in the first part of the 20th century, also impressed the painters. Salvador Dali wrote in 1935: "Nowadays physics is the new geometry of thinking." (2) In *The Persistence of Memory* the soft watch is "the Camembert cheese of the space and time" (Dali), and at the same time it reminds the viewer, who is familiar with special relativity, of the time dilation. According to an English professor "the cheese/watch is the metaphor of the curvature of Einstein's space-time. Later, after the Second World War … in the Dissolving of The Persistence of Memory … he explodes the cheese into pieces. This picture was inspired also by science, nuclear physics, first of all the explosion of the atomic bomb." (2)

The *Raphaelesque Head Exploding* was inspired by Dali's knowledge of *nuclear physics*. Here the Madonna face is depicted in a state of nuclear fragmentation.

In *Time Transfixed* Magritte portrays a train emerging from a fireplace and a clock on the mantelpiece, indicating stopped time, as *symbols of relativity*.

The elements of quantum mechanics, "models" of *wave-particle duality* (for example of electrons) and *complementarity* can be recognized also in some of the paintings of the previous centuries. George Seurat's paintings consist of dots (particles) or they show continual pictures (wave), in what we can recognize figures, things, or landscape – depending on the position of the spectator.

Sounds of music and noise made visible as physical models

The resolution and the analysis of the sounds and making them visible are also suitable to model several physical concepts. Instead of the well-known illustrations of the basic concepts of acoustics, let me present here some other examples.

The difference between the typical *types of the sound* can be a model of the difference between the *types of light emission*, as it is written in an article about Einstein (3): *"Light sources such as the sun and tungsten filaments produce plenty of photons of the same frequency, but they are out of step – they produce the optical version of random noise. Get all the photons to be coherent – to pay the same note at the same time – and the result will be a singular roar rather than a dull hiss."* (3)

Nowadays we can analyze the sounds using a computer program and well selected examples, so we can show and easily explain the characteristics of different sounds. But we also can apply them to model other physical laws. The basic ideas of the following examples originate from an excellent book and enclosed CD ROM (4).

Applying Fourier transformation, we can get a resolution of the complex tone (the sound of a musical instrument) to its spectral components - to the fundamental tone and overtones. We can think about this process, like one of the models for *the principle of superposition* which sometimes is mentioned as *Newton's fourth law*. In case of a sound source, several forces, which cause harmonic vibrations, are acting at the same time. The net influence of these forces produces a periodic vibration. The inverse process is the basis of the Fourier analysis: from a periodic motion we can determine the harmonic oscillations, from which it was created. The visible result can be seen using the mentioned computer program with three types of displaying following analysis of a sound.

The rate of the resolution has a limit because of *the Heisenberg uncertainty principle*. Here the uncertainty principle is expressed in terms of time interval and frequency.

Standing near to a transformer housing or a high-voltage transmission line we hear a typical humming sound associated with *magnetostriction*. The changing magnetic field causes change in the size of the iron plates or wires, and this is followed by the change of pressure in the air. We can make this effect visible by sound analysis (4).

One can think of *entropy* as a quantitative measure of the degree of the *lack of information*. Nowadays perhaps this is the best approach to make this quantity more familiar to our students: we can show it by presentation of the basis of the digital sound recordings. In this process we have to compress enormous quantity of data without a significant degree of information loss. The data compression depends on a given proportion of resolution and reduction of the sampling.

Conclusion

Numerous further examples could be quoted from the world of pictures and sounds which we can use as models of several physical phenomena and laws.

Summarizing let me mention two paintings.

What do we see in Salvador Dali's *Metamorphosis of Narcissus*? On the left side we see a sitting figure whose image is reflected on the pond water (like Narcissus in the mythological story), or a hand, holding an egg from where a flower is growing. If the latter image is not seen in this part of the painting, it is repeated, like an independent image, where we can not misunderstand this, like the main topic. Perhaps the depth of the space is the essential point, or the simultaneous depiction of the events which follow each other in the mythological story – in this case the time, the relative idea of the simultaneity is the essential element for the viewer. Pieter de Hooch: *A Music Party in a Hall* tells us information about perspective, musical instruments (sounds) and Amsterdam (the hall is based on one of the interiors of the Town Hall in Amsterdam).

The paintings and the sounds can model something for us, and the main topic of them depends on our fantasy, and on the level of our literary and scientific knowledge. If these motivations are deep enough, in this case the aim is the decisive point of view, whether the observer wants to emphasize something, to use like a physical, or any other model.

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Easy Java Simulation: A Modeling Tool for Physics Teaching and Learning

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Abstract

Easy Java Simulations (Ejs) is designed for teachers and students who want to create (or modify) scientific simulations. With Ejs, they can concentrate their effort in writing and refining the relations in the underlying scientific model, and dedicate the minimum possible amount of time to the programming techniques. We have found that, by creating a simulation, many teachers get a new perspective of the phenomenon they are trying to explain, which almost always increases their enthusiasm about the use of this technology with their students. An alternative approach, and a very promising one, is to let students modify the model in a simulation or create their own simulations, thus engaging in what educational researchers call constructive modeling.

A computer simulation is a computer program that reproduces a natural phenomenon through the visualization of the evolution of its state. Each state is described by a set of variables that change in time due to the iteration of a given algorithm. Computer simulations in an instructional context involve using the computer to model real-world phenomena in order to help students gain insights into the behavior of complex systems. Computer simulations can help students to understand invisible conceptual worlds of science through animation, which can lead to more abstract understanding of scientific concepts. Quantitative data can be manipulated and visualized to help students form a qualitative mental picture. Such complex experience can help students to identify patterns within simulations, and formulate explanations for phenomena in terms of models and theories. Simulations must not only allow learners to construct and manipulate screen "objects" for exploring underlying concepts, but they must also provide learners with the observation and manipulation tools necessary for exploring and testing hypotheses in the simulated world (Jonassen, 1996). Combined with graphical representations, simulations should allow learner to visualize abstract concepts and to link them to prior knowledge, thereby fostering conceptual learning. Students interacting with an instructional simulation gain a better understanding of a real system, process or phenomenon by exploring concepts, testing hypotheses, and discovering explanations (Lunetta and Hofstein, 1991; Mellar and Bliss, 1993; Raghavan & Glaser, 1995). This interactivity provides opportunities for students to modify their mental models by comparing the outputs of the model with their

expectations (Jackson et al., 1996), and to engage or motivate students to explore and couple actions with effects which will lead to understanding. Creating a simulation by oneself requires an extra effort. The starting point is a full understanding of the phenomenon and physics model being simulated. Normally, beyond an understanding of the physical model, the designer needs the programming and technical expertise to describe the phenomenon in computer language. Easy Java Simulations (Ejs) is a software tool designed for the creation of computer simulations. It is a medium for making, doing, creating and best of all, it can be used as a modeling tool. Construction, simulation, visualization, and analytic description of the physics model are linked during the creation process. With Eis, the task of creating a simulation is greatly simplified. That is, the majority of the programming work is done by automatic code generation based upon text-based instructions, mathematic formula about the model and menu/mouse selections from the designer creating the graphical user interface for the simulation. Java source code is generated automatically and compiled into class files. In addition, a jar file and the associated html pages are produced for users to view the simulation with a browser. This automatic code generation allows the Ejs user to concentrate on describing the model by defining the parameters related to the model, providing equations for the evolution of those parameters, setting the constraints between variables, and building a graphical representation. An additional advantage of using Eis is that it causes the designer who is building the simulation to think through the problem in a new way. Ejs was developed for an Open Source Physics Project at the University of Murcia, Spain. Ejs, and the simulations created with it, can be used as independent programs under different operating systems, or be distributed via the internet and run within html pages by most popular web browsers.

What makes E is different from most other tools is that E is is not designed to make life easier for professional programmers, but instead it was conceived by science teachers, for science teachers and students -- that is, for people who are more interested in the content of the simulation, the simulated phenomenon itself, and much less in the technical aspects needed to build the simulation program. Hence, Ejs provides a conceptual structure and simplified tools that allow concentrate most of designer's time in the description of the model of the phenomenon want to be simulated. The typical audience includes science teachers and researchers who have a basic knowledge of programming, but who cannot afford the big investment of time needed to create a complete graphical simulation. They may be able to describe the phenomena in their respective disciplines in terms of algorithms, but still need an extra effort to create a sophisticated, interactive graphical user interface. Most computer simulations of scientific phenomena can be described in terms of the model-control-view paradigm. This paradigm states that a simulation is composed of three parts:

- 1. The **model**, which describes the phenomenon under study in terms of
 - variables, that hold the different possible states of the phenomenon, and
 - relationships among those variables (corresponding to the laws that govern the phenomenon), expressed by computer algorithms.
- 2. The **control**, which defines certain actions that a user can perform on the simulation.
- 3. The **view**, which shows a graphical representation of the different states that the phenomenon can have. This representation can be done in a realistic or schematic form.

These three parts are deeply interconnected. The model obviously affects the view, since a change in the state of the model must be made graphically evident to the user. The control affects the model because control actions can (and usually do) modify the value of variables of the model. Finally, the view affects the model and the control, because the graphical interface can contain components that allow the user to modify variables or perform the predefined actions.

To further simplify the construction of a simulation, **Ejs** suppresses the control part, merging it half into the view, half into the model. Actually, modern computer programs are interactive, which means that the user can modify the program's logic by doing some gestures (such as clicking or dragging the mouse, or hitting the keyboard) with the computer peripherals on the program's interface (or view). Thus, the view itself can be used to control the simulation. On the other hand, if we want this interaction to have certain relevance within the program, these gestures on the interface need to trigger actions that affect the model's variables. Therefore, the best place to define these actions is in the model itself.

Creating a simulation in Ejs consists in defining its model and its view (i.e., the graphical user interface/GUI) and establishing the mutual connections needed for

- the correct visualization of the state of the phenomenon being simulated and
- the appropriate interaction of the user with the view (either to modify this state or to perform the actions defined on the model).

This explicit separation in parts reinforces conceptually the central role of the model of a simulation. It is the model which defines what the program simulates and how. There may be different views for a given model. Teachers can create the same simulation with different GUIs for different tasks or different students.

In addition to the Model and View, Ejs has one more component from which a simulation is built– the **Introduction**. For pedagogical or

scientific purposes, it is always helpful to include a description of what a simulation does, including the instructions on how to operate it and other information related to the simulation. This information appears in the **Introduction**, which is used to generate the content of the *html* web page. Therefore, there are three major parts to the interface: **Introduction**, **Model** and **View**.

Figure 1 shows an example of the **Introduction** for a Simple Harmonic Motion (SHM) simulation. Figure 2 shows the SHM simulation that is created with Ejs.



Figure 1: Content in the **Introduction** will be used to generate web pages for the simulation.

Figure 2: Java simulation embedded in web page created with Ejs.

The Model interface follows the **Introduction**, and has five sections:

- 1. Variables: As shown in Figure 3, all the variables for the simulation need to be predefined with specific data types (or dimensions for arrays). The initial value for the variables can be specified here or in the "initialization section". Users can group the variables into several pages under different names. For example, the SHM simulation has two tabbed pages for the variables. The variables defined in the "coordinate" page are those that specify the boundary for the simulated region on the screen and the timing information in the simulation. The variables defined on the "basic" page are those that correspond to the position and velocity in the X-Y rectangular coordinate system, the mass for the simulated particle, and the spring constant for the SHM, etc.
- 2. **Initialization** (optional): Different sets of initial conditions can be defined to simulate different cases for the same model (scientific phenomenon). Initial values for the array variables are usually initialized here.

3. **Evolution**: Figure 4 shows that the simulation will be created with 20 frames per second and that the "Runge-kutta 4th order" method is adopted for the numerical integration. The "Independent Variable" is *t*. When the user enters y in the "State" column and vy in the

"Rate" column, $\frac{dy}{dt}$ is shown instead, in order to specify the evolution condition $\frac{dy}{dt} = vy$. Notice that the equation for simple harmonic motion is transformed into evolution conditions:

$$F_{y} = -k \cdot y - b \cdot v_{y} - m \cdot g \text{ becomes } \frac{dV_{y}}{dt} = (-k \cdot y - b \cdot v_{y})/m - g,$$

where m and k are mass and spring constants. Simulations for different models can easily be created by modifying the equations with different forms.

- 4. **Constraints** (optional): Optional constraints or relations between variables can be defined here.
- 5. **Custom** (optional): Custom functions can be defined to be used in other sections in the **Model** or as a trigger action for the GUI in the **View**.

🔔 Easy Java Simulations - springv.xml			👍 Easy Jav	Simulations - spring	y.xml			
○ Introduction ● Model ○ View	○ Introduction ● Model ○ View							
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Figure 4: The evolution/constraints for variables.

Physics teachers and students have found it is easy to follow the above steps to specify the mathematics equations in the model for the simulation. These are the same steps they would use to describe SHM in their physics classes. A comparison between the two is shown in Table 1. It is this similarity that makes many science teachers feel, for the first time, they are able to create their own simulations with Ejs.

As shown in Figure 5, Ejs provides an easy-to-use interface to create the GUI for the simulation. Interactive graphic elements can be built with mouse drag and drop actions. The tree-like structure of

elements in the **View** is used to select and edit a particular element. Each element provides some characteristics for itself, called "Properties,"

Steps to describe model for	Steps to describe phenomenon in
simulation in Ejs	science class
1. Define the boundary for the	1. Define the coordinate system.
simulated region.	
2. Define variables and give initial	2. Specify initial conditions and
values.	related parameters
3. Provide evolution and	3. Provide scientific law or
constraints for variables.	relations.
4. Generate simulation by	4. Carry out numerical calculation.
numerical method.	

Table 1: Comparisons between steps to describe a model for the simulation in Ejs and steps to describe the same phenomenon in science class.



Figure 5: Creating the GUI for the simulation in Ejs.

which can be linked with variables defined in the model. The linking mechanism is a two-way, dynamic process. At any moment, the property of the element will reflect whatever value the linked variable holds, and vice versa. If the property changes as a result of an interaction such as typing in a new value or moving a scrollbar, the variable will receive a new value. For example, the "X, Y, Size X and Size Y" properties for the arrow were set to link with variables x, y, v_x and v_y in the model. Whenever x, y, v_x or v_y are changed with time in the model during the simulation, an arrow in the user interface reflects the change. Also, some elements have properties of a special type, which are called "Actions," to specify what to do when the user interacts with the element (e.g. Reset, Pause, Play). Once the **Model** and **View** have been completed, Ejs can generate the Java source code, compile the source to create class files,

compress all the class files into a *jar* file and make *html* pages with a single mouse click. The generated simulations will automatically pop up on screen for inspection. If any error occurs when trying to compile the source code, extended information is provided to guide the user to check for the specific pages in the **Model**.

Conclusion and implications:

Simulations can provide insight into the inner workings of a process – not just what happens, but also how and why. We all agree that the computer simulations are not a substitute for observation of and experimentation with real phenomena. Nevertheless, computer modeling with online simulations can add a valuable new dimension to scientific inquiry and understanding. Well-designed computer applications allow learners to use visual and kinesthetic resources to explore phenomena and to test theories so that they may eventually construct a web of connections between new information and information they already know. With Ejas, the task of creating a simulation is greatly simplified. Ejs users concentrate on describing the model by defining the parameters related to the model, providing equations for the evolution of those parameters, setting the constraints between variables, and building a graphical representation --doing scientific work instead of playing with software. So teachers/students could concentrate most of their effort to teaching/learning instead of technology! Teachers without programming experience have already created simulations for use in their curriculum after an introductory Eis workshop. We have found that, by creating a simulation, many teachers get a new perspective of the phenomenon they are trying to explain, which almost always increases their enthusiasm about the use of this technology with their students. An alternative approach, and a very promising one, is to let students modify the model in a simulation or create their own simulations, thus engaging in what educational researchers call *constructive modeling*.

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What Goes Up, Must Come Down; Modeling of Tidal Movement by Students

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Abstract

Everybody knows the rise and fall of the tides. A closer look at the origin of tides and the behavior of the tides in various ports reveals a wealth of interesting phenomena that may challenge students to analyze and to model. Fortunately, many data sources are now available on the Internet for prediction and measurement of the tidal movement. Each port has its characteristic tidal spectrum. When this spectrum is converted into sound, the peculiarities of the tidal movement in this port can be heard.

In this paper we present a model for the moon-earth dynamical system, yielding the tidal movement on an all-ocean world. We also look at data sources on Internet with tidal data, and reconstruct the harmonic analysis for various ports with advanced data analysis techniques. For the well-known tidal river Thames, we model the tidal behavior as a function of the tides of the North Sea.

Tides, a fascinating phenomenon

Introduction

The attraction between the Earth and another heavenly body (like the Moon or the Sun) causes them to move in an elliptical orbit about their center of gravity with opposite phases. For the Earth-Moon system, the center of gravity Z lies inside the Earth:

$$r_E = \frac{m_M}{m_E + m_M} r = 4.67 \times 10^6 \text{ m.}$$

The required centripetal force for the revolution about Z at the Earth's center A is exactly produced by the gravitational force:

$$m_E\omega^2 r_E = G \frac{m_E m_M}{r^2}.$$

The angular speed ω in the above corresponds with the sidereal rotation period of the Moon of 27.32 days, the time of one complete revolution with respect to the 'fixed' stars.

Obviously, the Earth is not a point at all. Each point on the Earth moves with the same ω and r_E feeling the same centrifugal force, yet experiencing a slightly different gravitational pull from the Moon or the Sun. So, while the attractive gravitational force is exactly balanced by the centrifugal force in A, there remains for all surface points a net effect called the tidal force that by its nature only occurs for extended objects (the tidal force in A is naturally zero).



Fig. 1. Attraction of Earth surface points by the Moon, top view (the Earth seen on the North

Therefore, a surface point like a liter sea water experiences a tidal acceleration due to the discrepancy of the gravitational and the centrifugal acceleration:

$$\overrightarrow{a_{tidal}} = G \cdot m_M \left(\frac{\vec{s}}{s^3} - \frac{\vec{r}}{r^3} \right)$$

To complete this picture historically proposed and elaborated by great scientists like Newton, Bernoulli and Laplace, the Earth is simplified to an all-ocean world with the Moon in the equatorial plane. This model yields the so-called equilibrium tide that explains many tidal features such as periodicity, inequalities between successive high waters and low waters, and the occurrence of spring tides near full and new moon. Before this theory, the tides were frequently explained as being generated by the ocean breathing in and out and other unrealistic concepts.

Misconception!

At the side facing the Moon or the Sun, the attractive force wins from the centrifugal force while at the opposite side the centrifugal force is largest. Although on the one hand this explains that a particular surface point meets two high waters a day by the Earth's rotation, on the other it also suggests the widely spread misconception (even amongst physicists) that high water should be the result of the Moon's gravitational pull. But how could the *radial* component of the tidal acceleration (about $10^{-7} \cdot g$) pull this off against g of the Earth itself? Obviously it will disappear completely in the balance of the dominant normal (or buoyant) force and gravity. By contrast, tidal waves on Earth are determined by the remaining *tangential* components of the tidal force field called the *tractive* force. The dominant component after decomposition of $\overline{a_{itdal}}$ into radial and tangential components is calculated to be

$$a_{\varphi} = -\frac{3}{2} \frac{G \cdot m_M}{r^3} \cdot R \cdot \sin 2\varphi$$

(with *R* the Earth's radius) which is maximal for $\varphi = 45^{\circ}, 135^{\circ}$. With respect to the Moon, the angle φ varies with a period given by the relative angular speed: $\varphi = \omega t = \frac{2\pi t}{T}$. As a result, the tidal force varies by

$$2\varphi = \frac{2\pi t}{\frac{1}{2}T}$$

and so by half the period *T*, explaining the periodicity of the semidiurnal (two-daily) M2 tide:

$$T = \frac{1}{2} \left(\frac{1}{23.93} - \frac{1}{27.32 \times 23.93} \right)^{-1} = 12.42 \text{ h} = 12 \text{ h} 25 \text{ min.}$$



Fig. 2. Tractive force field (image from Navy Operational Ocean Circulation and Tide Models at <u>www.oc.nps.navy.mil/nom/day1/partc.html</u>)

However, objects like the moons of Jupiter *do* experience a strong 'massage' of the radial force, which explains the existence of volcanism (Io), the presence of subterranean liquid water and even the possibility of life (Europa). If a satellite approaches its planet close enough for the radial tidal force to equal the satellite's gravity, it will be torn apart by tidal disruption. The rings of Saturn lie inside this Roche limit:

$$R_{c} = R_{planet} \sqrt[3]{\frac{2\rho_{planet}}{\rho_{satellite}}}$$

Towards a model

We assume that for an equatorial sea channel, the work done on the water fully originates from the tidal acceleration:

$$a_{\varphi}Rd\varphi = gdh$$

This immediately yields:

$$\frac{\mathrm{d}h}{\mathrm{d}t} = \omega \frac{\mathrm{d}h}{\mathrm{d}\varphi} = \omega \frac{a_{\varphi}R}{g}.$$

Together with the expression for a_{φ} given above, this equation can now be used in a dynamical system model as shown below in Figure 3. This over-simplified all-ocean model turns out to give an M2 tidal amplitude of 27 cm. A similar model including the Sun as well yields interference effects as neap and spring tides (when Sun and Moon align).



Fig. 3. Graphical models of the all-ocean equilibrium tide. Left: Moon only, M2 tide. Right: Moon and Sun combined, M2 plus S2 tide.

Tidal friction

The Earth does not respond immediately to the Moon's location, as energy is dissipated in making the tidal bulges. Tidal friction, prolonging the Earth day by 1.6 ms each century (dissipation of 2×10^{12} W), is strongly influenced by the distribution of land and water and thus by the continental drift. The 'flood crests' are carried along by the planet's rotation; the instantaneous tidal forces partially counteract, causing a dragging effect. The Moon withdraws from the Earth for this reason by 3.7 cm a year, due to conservation of angular momentum: as the Earth's spin diminishes, the orbital angular momentum should increase. This process will continue until the spin and orbital periods are equal and month and day coincide! (This future month-day will actually become some 50 of our present days.)

By the same effect, the spin of the Moon itself equals its revolution period. Therefore, the Moon continuously faces the planet with the same (heavy) side, like almost every other satellite (and Mercury towards the Sun) in our solar system. Tidal dissipation thus accounts for the spin and rotation states of all celestial binaries. The endpoint of tidal evolution is a circular, synchronous orbital motion (Pluto and Charon).

Shortcomings of the model

Deviations from the above model arise because the Moon usually lies outside the equatorial plane, exhibiting a declination instead. As a result, the two height maxima during a natural day will have different amplitude: the daily inequality. In addition, the Moon moves in an elliptical rather than in a circular orbit, causing a variation in r of 10% and thus in r^3 of 30%.

The presence of land not only makes high and low water observational, it also changes the local phases and amplitudes in a dramatic way, both at sea and over land. Only the period is directly recognizable while many higher harmonics like M4, S4, and so on are produced. To describe and accurately predict tidal effects at seaports harmonic analysis is indispensable. To study the change in phase and amplitude as the tide runs up from a seaport into a convergent estuary, the behavior of a tidal wave must be modeled.

Harmonic Analysis of Tides by Students

Introduction

Because of the geographic position and the size of the Netherlands every inhabitant is familiar with tides. Sea level rises and falls cyclically on a twice-daily basis and the graph of a tidal motion, measured or computed for a coastal place or an oil platform, is periodic. A periodic function can be described with sine functions. Tidal curves are always approximated in Dutch mathematics textbooks by single sine functions. Students search on Internet for tidal data of a coastal town on a certain day or the yearly average, and then they try to match the data found with a good sine fit using graphical software or a graphing calculator. It's true that limitations of this simple mathematical model are briefly discussed and that in particular the asymmetry between low and high tide is pointed at, but textbook authors do not go further than a short reference to harmonic analysis and a pointer for background information at a website like www.getij.nl. They suggest students to explore tidal motion further in practical work or a research project, but they do not give any clue of how to do this with a chance of success. A citation of Jan de Lange (2000), in a paper on studying tidal motion in the classroom, is hardly encouraging: "The students don't have the tools to find a better way of coping with the lack of symmetry of the real graph." As we shall see, the situation in 2006 has changed: in the Coach 6 environment (Mioduszewska & Ellermeijer, 2001) students have access to a state-of-the-art signal analysis tool that allows a more realistic description of tidal motion.

Harmonic analysis of tidal motion

The tides in the North Sea are semidiurnal, that is, you have (more or less) two cycles per day, the two low waters of each tidal day are almost equal in height, and the same holds for the two high waters. See the screen shot below (Fig. 4) of a diagram with the predicted tidal data (black dots) at Flushing from May 21 till May 23, 2006. In the same diagram are shown two regression curves of these data: a sine fit (red) and a better approximation with a sum of two sine functions (blue), which is determined via the Prony method for spectral analysis (Mackisack et al, 1994).



Fig. 4. Predicted tides at Flushing from May 21 till May 23, 2006, and two approximations of the tidal curve.

Tidal currents are not everywhere on earth of the same type: there are coastal areas with a diurnal cycle, i.e., with a period of approximately 24 hours, and there are locations on earth where you have two cycles per day, but the two high waters and the two low waters have marked differences in their heights.

Official tide tables for almost all coastal areas on earth can be found on Internet. This enables students to find places and time periods for which the tidal model of a single sinusoid works well. You can find for example on the website <u>www.tidesandcurrents.noaa.gov</u> of the National Oceanic & Atmospheric Administration in the United States of America the tidal data for Sewells Point, Hampton Roads in Virginia, from March 13 till March 15, 2006. The screen shot below (Fig. 5) shows the predicted tidal data (black dots) and the best sinusoidal model (red). The graph of the differences between predicted water levels and the outcomes of the sinusoidal model (residual graph in gray, with its own coordinate system) reveals that the simple sinusoidal model is accurate up to 3 cm.

Do not draw the wrong conclusion that the tides at Sewells Point in Virginia are always well described by a sinusoidal model. Figure 6 shows the tidal data from March 23 till 25, 2006, an approximation with a single sine function (red) and a better approximation with a sum of two sine functions (blue), which is determined via the R-ESPRIT method for spectral analysis (Mahata, 2003).



Fig. 5. Tides at Sewells Point (Virginia) from March 13 till March 15, 2006, and the tidal graph approximated with a sinusoidal model.



Fig. 6. Tides at Sewells Point (Virginia) from March 23 till March 25, 2006, and two approximations with sine functions.

In order to get an adequate mathematical model of the tides with sine functions for a longer time period you must add more terms ('harmonic constituents') of the form $H\sin(\omega t + \phi)$. In Coach this can be done best via the R-ESPRIT method. In this method you can set two parameters: the snapshot dimension, which determines the length of the sequence of consecutive data that is used in the harmonic analysis, and the number of sine functions present in the mathematical model. If you model the predicted tides at Sewells Point in 2005 with 8 sine functions, then you get with the following formula with the automatically chosen snapshot dimension equal to 84:

 $41.11 + 35.12\sin(28.982\ t - 75.637) + 6.38\sin(30.002\ t + 6.794) + 4.97\sin(15.052t\ -152.698) + 4.95\sin(13.946t\ + 78.075) + 0.45\sin(0.200\ t + 106.750) + 0.96\sin(27.990\ t + 92.143) + 0.02\sin(31.472\ t - 24.033) + 0.02\sin(33.216t\ + 103.765),$

where t is the time (in hours) from the beginning of 2005 and the speed of each constituent (if you wish, the frequency of each sine function) has the in tidal analysis commonly used unit of degrees per hour. The standard deviation turns out to be about 8 cm. You can extend this model to 18 harmonic constituents by applying the same spectral analysis to the difference of the predicted tides and the approximation already found. The next eight constituents are:

 $0.11 + 7.70\sin(28.438t + 60.437) + 4.06\sin(0.049t - 177.360) + 1.30\sin(15.067t - 37.467) + 0.38\sin(57.963t - 79.633) + 0.06\sin(29.475t - 77.609) + 0.05\sin(30.721t + 106.212) + 0.02\sin(13.569t - 164.1467) + 0.01\sin(43.806t - 43.641)$

The standard deviation of the model with 16 sine functions is about 5 cm. In Table 1 we compare the five most important contributions in our Coach model with literature values of the harmonic constituents:

Coach m	odel	Literatur	Literature data			
speed	amplitude	speed	amplitude	label		
(°/h)	(cm)	(°/h)	(cm)			
28.982	35.12	28.984	36.6	M2		
28.438	7.70	28.440	8.1	N2		
30.002	6.38	30.000	6.4	S2		
15.052	4.97	15.041	4.9	K1		
13.946	4.95	13.943	4.2	01		

Table 1. Comparison of the principle harmonic constituents at Sewells Point (Virginia) found in Coach and provided by the National Oceanic & Atmospheric Administration in the USA.

You may call this agreement between the Coach model and the literature values astonishing. The sixth most important contribution in the model with speed 0.049 degrees per hour and amplitude 4.06 probably corresponds with the harmonic constituents labeled SA and SSA, which describe the yearly meteorological variations and their influence on the sea level. The labels M2 and S2 belong to the harmonic constituents that are linked with the motion of the moon around the earth and the motion of the earth around the sun, respectively, and which cause the semidiurnal tide. The N2 constituent takes into account the effect that the orbit of the moon around the earth is in reality not a circle but an ellipse. The diurnal constituents K1 and O1 take into account (amongst other things) the inclination of the earth's equatorial plane with respect to the plane of the moon's orbit. Most (if not all) harmonic constituents can be related to

astronomical phenomena and therefore a tidal prediction is often referred to as astronomical tide. In practice, the number of constituents needed for accurate tidal predication and the amplitude, speed and phase of each harmonic constituent are often determined from tidal records of three consecutive years. As a matter of fact, the speeds are always fixed and only the amplitudes and phases of the strongest tidal constituents that have propagated to a point of interest must be determined by regression methods. Short term tidal constituents (say for data periods up to one month) are also determined by the Fourier harmonic analysis method that we use in our work. We refer to the NOAA report 'Tidal Current Analysis Procedures and Associated Computer Programs' (Zervas, 1999) for detailed information.

Tidal analysis becomes more interesting for students when they can investigate tidal motion closer at home. Figure 7 is a Coach screen shot of a tidal analysis of two consecutive days at Europahaven (May 24-25, 2005). It shows that the phenomenon of double low water (also known as agger), which means that the low water consists of two minima separated by a relatively small elevation, can be modeled well by harmonic analysis. Actually the model consists of a fundamental tidal speed and overtides, i.e., harmonic constituents with a speeds that are an exact multiple of the fundamental constituent.



Fig. 7. Screen shot of modeling double low water at Europahaven (May 24-25, 2005).

In order to get good results with the R-ESPRIT method, which are in good agreement with recorded data or official tidal predictions the choice of the snapshot dimension is important. You must determine this parameter by trial and error in case no suitable value less than or equal to 100 has been found automatically. For example, we have found for the location Roompot-Buiten in the Oosterschelde the following six constituents on the basis of tidal data from 2005 (Table 2).

The astonishing agreement between our spectral analysis with Coach and the literature data of RIKZ (2006) has been accomplished by choosing a snapshot dimension of 521 for a model with eight sine functions. The best snapshot dimension less than or equal to 100 leads to the first two constituents only. Admittedly, it is a bit of a puzzle to find a suitable snapshot dimension, but in this way students might learn to look

Coach me	odel	Literature data			
speed	amplitude	speed	amplitude	label	
(°/h)	(cm)	(°/h)	(cm)		
28.980	131.1	28.984	135	M2	
29.996	36.3	30.000	36	S2	
28.457	15.3	28.440	22	N2	
30.098	10.5	30.082	10	K2	
13.956	10.5	13.943	11	01	
27.995	4.9	27.968	11	μ2	

critically at mathematical models and computed results presented to them in future.

Table 2. Comparison of the principle harmonic constituents at Roompot-Buiten found with Coach and provided by the National Institute for Coastal and Marine Management.

Tidal waves in convergent estuaries

The dominant influence on the tides in estuaries is the change of water depth and estuary width as the tide propagates up the estuary. The shoaling and narrowing of the estuary slows the progress of the tidal wave, increasing its amplitude. At the same time, there is a damping effect of channel friction balancing the tidal amplification in shallow estuaries (Friedrichs & Aubrey, 1994; de Swart, 2006).



Fig. 8. Description of a tidal wave by the relative height \zeta and the flow Q.

Tidal waves may be described by the de Saint-Venant equations. Using the Lorentz linearization procedure for the quadratic friction (Lorentz, 1922; Labeur, 2006), they can be simplified to a telegraphist's equation:

$$\frac{\partial^2 \zeta}{\partial t^2} - c_0^2 \frac{\partial^2 \zeta}{\partial x^2} + \kappa \frac{\partial \zeta}{\partial t} = 0.$$

Here, $c_0 = \sqrt{gh}$ is the frictionless wave speed and κ the linearized friction factor. In a prismatic channel (constant width and depth), this yields a simple traveling wave as a solution:

$$\zeta(x,t) = A e^{-\mu x} \cos(\omega t - kx + \varphi).$$

Here,

$$\mu = k \tan \delta$$

is related to a 'friction angle'

$$\delta = \frac{1}{2} \tan^{-1} \left(\kappa / \omega \right)$$

that in turn is determined by the friction factor κ .

In a model, we want to study the progression of the tidal amplitude and phase along an estuary like the river Thames. Following the stockflow philosophy of graphical modeling, it seems logical to introduce bathtubs of 1m length of Thames water with given in- and outflows. The instantaneous water volume divided by the width then directly yields the height as a function of time. Not surprisingly, this height lags behind the inflow by the friction angle δ . First, we study the situation at Coryton:



Fig. 9. Graphical model of the tidal wave at Coryton.

To continue, we assume an exponential behavior for the width and the average depth of the Thames as a function of distance along the river:

$$B(x) = 4000 \exp(-x/25)$$
 and $h(x) = 12.5 \exp(-x/79)$.

Furthermore, the river is subdivided into seven prismatic sections, each with a constant width and depth determined by the one meter bathtub in the middle. To achieve a more quantitative picture, some assumptions on the inclination of the banks are made:



Fig. 10. Modeling of the river cross section.

Due to the flattening of the banks, the quantity ζ deviates only slightly from a pure sinusoidal function. Fitting ζ to a sine function with ω fixed to the M2 frequency yields the requested phases and amplitudes.

The full model is a straightforward extension of the above, each section being a copy of the former with corresponding changes in distance, width and depth. Obviously, phase and amplitude matching has to be applied at the transition of each section. As can be seen from Figure 11, both the amplitudes and the phases now turn out to correspond reasonably well with experiment. Please note that the amplitude almost linearly increases during the first 20 km, reaches a maximum at 33 km from the mouth (actually at the Tidal Barrier at 40 km) and then decreases again. The data are compared to the results of Green's classical theory for amplitude amplification, that does not take into account frictional effects.



Fig. 11. Tidal amplitudes of the river Thames as a function of distance.

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Teaching Wave Physics Through Modeling Images: Use Of Cabri[®] To Address Water Waves Geometrical Models And Basic Laws

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Abstract

Researches about students' difficulties in understanding mechanical wave phenomena have addressed issues as: propagation, superposition principle, mathematical description, sound, etc. Historically, instructional materials as experiments with slinkies, taut strings and ripple tanks have been proposed to address such difficulties. Since a few years, dynamical images as Java applets or Shockwave interactive movies, available through the web, are used to address difficulties related to the dynamic character of wave phenomena. Nevertheless, despite the many potentialities, such interactive simulations based approaches rarely allow significant modeling activities in wave physics due to the use of implicit built-in mathematical models. Since models of mechanical waves involve geometrical entities and their relations, the software "Cabri® Géomètre", though seldom used to model complex physical phenomena, well fits to actively engage students in modeling activities such as the construction of wave fronts, derivation of the basic laws of reflection, refraction, and interference. In our approach, point-like sources, circles, lines, angles are drawn directly on digital photos of water waves produced in a ripple tank. This allows to observe together and compare the realistic image and the schematic one and favor understanding of the meaning of the quantities defined in the geometrical model of waves. By means of Cabri® utilities, measures of wavelength or angles are carried on, allowing the derivation of the $\lambda = c/v$ relation and of the laws of reflection, refraction, interference pattern. Examples of activities exploiting such approach will be discussed.

Introduction

Investigations on students' difficulties about wave phenomena have been carried out only since nineties (Snir, 1989; McDermott, 1990; Linder, 1992; Maurines, 1992; Grayson, 1996; Grayson & McDermott, 1996). Results of investigations show that main difficulties are: - expressing "what a wave is"; - distinguishing medium's perturbation and wave propagation; - understanding what is transported by a wave; - separating "what propagates" (i.e. perturbation of medium's shape) from "what oscillates" (i.e. motion of medium's element); - identifying velocity dependence on medium's properties; - identifying main physical variables (amplitude, frequency, wavelength); - dealing with non-harmonic impulses; - distinguishing/relating displacement of a medium's element vs. time and medium's configuration at a given time; - characterizing wave propagation via a mathematical function. These research results allowed the design of instructional materials (McDermott et al., 1998).

Other research-based instructional materials, exploiting a digital video approach, have been recently developed by Wittmann (Wittmann, Steinberg & Redish, 1999; Wittmann, 2002). Together with these works, in the past few years, one can find on the web java applets, animated gifs etc, and easy-to-find simulations as helpful sparing-time tools useful to address waves physics, an intrinsically dynamic process¹¹. Despite these advantages and the ever increasing grade of interactivity of many up-todate simulations, the students are seldom engaged in active participation of building/justifying the models, both descriptive and interpretative, of waves phenomena. On another hand, research has proved that, if not accurately designed, use of iconic representations, may cause difficulties in students' interpretation of underlying physics concepts¹². Therefore, an aim of research on wave physics teaching is to take into account such issues when designing instructional strategies focused on this physics field.

Cabrì[®] based approach to mechanical waves

In the framework of mechanical waves physics, we describe here a *modeling images* approach aimed at the construction of descriptive models of simple wave phenomena, easily reproducible in classroom activities and in pre-service teachers' interventions by means of the well-known ripple tank apparatus to produce water waves. Water waves experiments have been proposed since long time (PSSC, 1971) in the teaching of mechanical waves. Images produced on an opaque screen show the main features of wave phenomena as propagation, reflection, refraction, interference, diffraction, Doppler effect, etc... Despite their potentiality to provide students an easy way to observe properties otherwise difficult to study, ripple tanks experiments are frequently used in every-day classroom activities as demonstrative ones, and performed by teachers themselves.

The *modeling images* approach, based on research results of our group (FFC, 2003; Sassi, Lombardi & Testa, 2004; Testa et al., 2004) allows to improve the learning potentialities of images produced by ripple tank, guiding students to build autonomously descriptive models of wave phenomena. The method is based on manipulation of digital photos of ripple tank screen (taken with a commercial CCD camera) by means of the dynamical geometry software Cabri[®] Géomètre¹³. The reasons for proposing this tool are that:

¹¹ See for example the NTNU JAVA Virtual Physics Laboratory by Fu-Kwun Hwang

http://www.phy.ntnu.edu.tw/ntnujava/

¹² Some of the results of the STTIS (Science Teacher Training in an Information Society) Project on iconic representations have been published in *Int. J. Sci. Ed.* **24** (3) 227-341

¹³ <u>www.cabri.com</u>

- modeling framework of mechanical waves is *geometrical* (wavefronts are identified as circles and lines, circular waves' sources are supposed to be point-like, directions of propagation are represented by lines/arrows normal to wavefronts, laws of reflection, refraction and interference are usefully described in terms of angles and distances between points in the plane). The fact that Cabri[®] allows the user to easily create and manage such geometrical entities makes it the most natural software choice to implement basic modeling activities concerning mechanical waves instead of other general purpose software which feature drawing facilities/tools;

- Cabrì[®] allows not only to draw geometrical patterns on real images (for example a line to approximate a finite thickness wave front, or a point to approximate a "real" source), but also to *measure* the distance between two lines or between a point and a line or circle, the amplitude of an angle or to establish if a line is parallel or perpendicular to another; hence it allows to quantitatively estimate, up to a well defined degree of uncertainty, physical quantities of wave propagation phenomena.

In this way, "iconically rendered" approaches which go by means of graphical approximations from the real phenomenon to an ideal geometrical world may be implemented.

In the following paragraphs, some examples will help clarifying the details of such an approach.

Examples of applications of the approach

As previously said, geometrical modeling is a straightforward approach to understand water waves. Consider the wavefronts pattern of a *40 Hz* plane wave in Fig. 1a.

A first step of the descriptive modeling methodology consists in substituting the wave troughs (the brighter and thinner zones; the wave crests are represented by the dark zones) with lines to build the wavefront pattern. The activity engages students in choosing the best line that approximates the wave troughs. An example is shown in Fig. 1b.

At this stage, a comparison of the real world "object", i.e. the finite thickness bright strip, and the geometrical model "entity", i.e. the line, can be useful to address the concept of wavelength as the distance between two consecutive lines representing wavefronts and to relate this parameter to the distance traveled by the wave in the plane. Moreover, measurements using the "Distance or length" function of Cabri[®] environment, can be analyzed¹⁴ by means of a spreadsheet allowing to demonstrate the overall constancy of the wavelength parameter with a high degree of precision, hence to give plausibility to its key role in describing wave propagation. Accurate measurements of wavelengths λ_i

¹⁴ The complete procedure is described in a forthcoming paper.

at different frequencies v_i can then be used to give plausibility to the fundamental relation $\lambda = c/v$ by graphing λ_i as a function of values $1/v_i$.



The same procedure can be performed to study circular waves patterns. In this case, it is useful to address how one approximates the finite dimension wave source with a point from which several concentric circumferences depart and propagate on the plane, and the "real" wavefront with an ideal circle.

Another interesting case is the analysis of two point-sources interference. A typical interference pattern (frequency = 50 Hz) is shown in Fig. 2a.

First, we substitute real sources with points (S_1 and S_2 in Fig. 2b); then crests (dark zones) and troughs (bright zones) with concentric circles centered in S1 and S2 in order to adequately represent the interference pattern. In Fig. 2b, circles which approximate crests and troughs are drawn respectively in black and grey. The geometrical model is then improved by identifying intersection points between crests-troughs (water at rest, *nodes*), or crests – crests, troughs-troughs (water undergoing maximum perturbation with respect to equilibrium level, *anti-nodes*).

Cabri[®] helps students to recognize in an easy way these nodal and anti-nodal points as intersections of circumferences and also that such points all lie along distinct lines (actually points can be joined by segments which roughly form a line), symmetric with respect to the so-called central anti-nodal line, which approximately represents the axis of the segment joining S₁ and S₂ (Fig. 3a and 3b).





Using the "Distance and Length" and "Measure Transport" Cabri[®] functions, for each node or anti-node, one can measure their distance

from the sources S1 and S2 and determine the path difference in that point (i.e. the difference in distance traveled by the two coherent water waves). A further analysis of the drawn pattern can help to recognize that all points on a given nodal or anti-nodal line can be characterized by approximately the same path difference (see Fig. 4a and 4b, the measurements are expressed in arbitrary units).



The model of anti-nodal and nodal lines geometrical pattern can be quantitatively analyzed by studying the path difference in points located on the intersection of nodal and anti-nodal lines with a line parallel to the segment which connects the two sources (see Fig. 5a and 5b) as a function of whole-numbers (points on anti-nodal lines) or half-numbers (points on nodal lines). In this way, the plausibility of the relationship between path difference and wavelength can be investigated and more plausibly supported.
Fig. 5a. Nodes (filled circles) are marked on a line parallel to the segment joining S1 and S2 to study plausibility of interference laws. Central anti-nodal line is white



Fig. 5b. Anti-nodes (crosses) are marked on a line parallel to the segment joining S1 and S2 to study plausibility of interference laws. Central anti-nodal line is white



Discussion and future work

The above examples show that the *modeling images* approach allows to: - perform measurements of wave's characteristic parameters. One of the main problems in using ripple tank has been that of realistically reproducing with paper/pencil the wave patterns produced on screen. A naïf method for performing measurements consists in placing a sheet on the screen. This makes it difficult to draw precise lines and curves; as a consequence the performed measurements have a low level precision. The presented approach can improve dramatically the precision of measurements (also easily reproducible) and, due to its simplicity and straightforwardness, it can be easily implemented in high school laboratory courses, integrating experiments with computer activities. Moreover, digitalization of the photo shots helps to overcome difficulties with image quality since basic color filters are now available in all downloadable shareware software. Finally, our approach allows to reflect on the influence of parameters such as photo resolution, brightness, contrast on the precision of the measurement. This can be a way to introduce students to the themes of sampling and representing continuous data, and gives them the opportunity to enrich their learning of physics and related technologies;

- give plausibility to a descriptive geometrical model of mechanical waves. As said above, research has shown that many students' difficulties with waves physics concern dealing with abstract entities which describe wave phenomena as wavelength, wavefronts. The modeling images approach addresses specifically such difficulties since it allows to construct the geometrical model starting from the "real wave propagation pattern". The potentialities of water tank experiments, iconic representations and simulation environment are *jointly* used to get a more clear picture of phenomena: abstract descriptive entities are not only "seen" but geometrically represented and manipulated, therefore students can be helped to develop a deeper formal knowledge of wave physics. Moreover, the students are highly involved in the learning process since it is up to them to choose the line or circle which best represents experimental wavefront; finally, using Cabri[®] dynamical control of geometrical entities, students can exploit a "what happens if.." approach, investigating effects of other choices of lines or circle on the whole wave pattern, hence deepening the understanding of the role of model's parameters (as wavelength).

Future work includes the improving of the geometrical model, the application of our approach to measurements of other wave phenomena (as Doppler effect) and the comparison with measures performed with other modeling software tools; it is also planned to design a wave tutorial both for students and pre-service teachers and to further investigate issues such as software precision and image resolution influence on measurements.

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Learning Quantum Mechanics

Visualization of Hydrogen Atom States

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Abstract

In an introductory university course on quantum physics we found that students often misinterpret polar graphs and hydrogen eigenstate probability density plots. This paper describes our project designed to improve this and the project outcomes. The students solve different tasks from their workbook using small special designed programs which enable them interactive work with graphs and to build their understanding of the plots. The tasks were designed according to experiential learning approach. Described activity was part of the standard introductory course on quantum mechanics for future physics teachers. Students found the project useful and interesting.

Motivation: Why have we done this?

According to research (Buddle et al., 2002a) and our experience, learning a quantum atomic model raises many difficulties. Many students imagine the atom like the Bohr's model – electrons like planets moving around the nucleus. Although some of them realize that this is not correct, Bohr's concept seems to be very persistent. (Müller & Wiesner, 2002) Detailed survey of various students' preconceptions and teaching difficulties can be found in Buddle et al., 2002a. There are new approaches how to deal with students' problems and lead them to better understanding (Buddle et al. 2002b, Niedderer & Deylitz 1999, Müller & Wiesner, 2002). They all call for using appropriate images and pictures.

Besides these conceptual problems our experience shows that for students it is very difficult to imagine the spatial probability density of hydrogen atom eigenstates. Especially the polar and spherical plots (most common in textbooks) are difficult for students to understand.



And your views?

Let's make a test



1. Is this statement true?: "On the left picture we can see shape of some orbital. An electron can be observed only inside the red bubbles and cannot be observed outside." ¹⁵

2. No matter how you answered the previous question, try to choose the correct spatial shape for the previous planar cut from the three images on the right-hand side.¹⁶

We were looking for a tool which would help students to understand *step-by-step* how the angular and radial part of hydrogen eigenstate functions determine the orbital shape. We can easily find many images of atom orbitals in textbooks, various pictures and applets can be also found in the internet (e.g. Falstad 2005, Manthey 2004) or in other publications (e.g. Brant et al. 2003). However, all of them show only spherical harmonics (in polar graphs) and some of them also plot the probability density. Because we were unsuccessful in our search for a suitable interactive tool, we made it ourselves.

Realization: What did we do?

We designed a set of **interactive tools** that visualize the radial and angular part of wave functions and probability density plots of hydrogen atom eigenstates in variety types of graphs. Computer tools allow very good visualization of functions, better then common printed images. Computer generated graphs are accurate, not only hand-drawn shapes as in some textbooks. Moreover, good images and interactivity (e.g.: zoom and rotation of 3D graphs) can increase students' interest. The programs were accompanied by a



Fig. 1: Program 3D_line

workbook containing tasks, results and explanations (and some small hints how to use the programs as well). The workbook was designed to lead students to active working and thinking. They should construct he entire wave function step-by-step from its parts. After each step they can check if they interpret pictures correctly. For designing the tasks it was crucial that students could correct their answers themselves, using only the computer tools, and learn from their own mistakes.

The project was designed for and tested out on the 2nd-year university students. But before we present outcomes of the project, we describe computer tools and workbook in more details.

¹⁵ No. On the picture is shown only the angular part of the probability density of the chosen eigenstate. The length of the "bubble" means only that it is more probable to find an electron in this direction. To obtain the probability of electron observation, we have to combine this angular part with radial part. As well as electron observation "prefers" some directions, it prefers some distances from the nucleus.

¹⁶ The 2nd image is correct.

1. Computer Tools This part could be difficult to follow without the computer tools.



Fig 2: Program Legendre_2D

The computer tools were made to let students see and compare different methods (in different types of graphs) of spherical functions visualization. However, the aim is not only to visualize functions. We enriched the tools by special properties that enabled us to prepare tasks for the workbook. All programs used in our activities were made in the LabVIEW environment. The programs were compiled to run without having LabVIEW completely installed. At least the

LabVIEW Runtime Engine is required. The Runtime Engine and all tools can be downloaded for free from our website.

The first tool (program), 3d_line (Fig. 1), is very simple. It draws a line for given angles theta, and phi, in spherical coordinates. While using this program, students should remember spherical coordinates and familiarize with them. If you want to use polar graphs, it is necessary to understand spherical coordinates very well.



The second program, Legendre_2D (Fig. 2) offers three different views of Legendre polynomial of the argument cos \mathcal{G} . The function is selected by entering the

Fig 3: Program Legendre 3D

quantum numbers *l* and *m*. The first row of graphs contains the function itself; in the second row is the square of it (angular part of density of probability as we will see later). Figures on the left are "classical" XY graphs, the middle ones show the density of probability by intensity of color, and the figures on the right are polar graphs (most used). All of the figures may be switched on or off independently. This feature is used during the students' tasks.

In the next step we add the third dimension and deal with the angular part of probability density. In the program Legendre_3D (Fig. 3) students enter the *l* and *m* quantum numbers and the program shows the angular part of the probability density (square of the appropriate spherical harmonic). Two figures in top line are identical to the graphs in the previous program: the color intensity graph and the polar graph. The bottom line contains a spherical cut through space (left one) – the intensity of color agrees with function value – and a standard 3D polar graph (right one).



Fig 4: Program 3D_orbitals

The last program, 3D_orbitals (Fig. 4), contains both angular and radial parts of probability density of hydrogen atom eigenstates. Besides the graphs of the radial part of the function (bottom left) and angular part (top left and top middle), the program also shows their product in the form of planar cut (top right, the cutting plane contains *z* axis) and spherical cut (bottom right). The radius of the spherical cut may be

changed. The actual value of the radius is shown in the graph of the radial part and in the planar cut in the form of a yellow line / circle.

Because the maxima of the radial part of the wave function are not of similar height, the graph of the probability density for finding an electron has a "brightness zoom" (see fig. 5). The entire graph can be brightened by moving the blue pointer on the color scale. Places with a value higher than the slider position are marked by white color. These figures show the proper shapes of orbitals, i.e. areas where the probability of finding electron is significant.



Fig 5: Brightness zoom

2. Workbook

The computer tools are accompanied by a workbook. It has 14 pages with approximately 25 various tasks. We assumed that it would take students about 2 hours to fill it in.

The topic (solving the Schrödinger equation for the Coulomb potential in an *x*-representation) was lectured previously. The workbook supposes such previous knowledge, but crucial parts are remembered and summarized there. According to our experience, students' understanding of this topic after only following the lecture is not very deep and they are not able to imagine the function correctly. We assumed that after solving the tasks, students would build up their own spatial image of the orbitals. The tasks were based on students' active work. Besides the more common questions we used so-called "redrawing" tasks for which the computer tools were equipped by the independent graph switching. Follow fig. 6: At first the students switch off all graphs, adjust quantum numbers and switch on only one of the graphs (left part). Then they try to redraw it into the other types of graphs in their workbook. In the middle you can see one of students' solutions. Finally they switch on all graphs again and correct their work themselves. Then students repeat "redrawing" with modified initial softings ______ different quantum numbers.

"redrawing" with modified initial settings – different quantum numbers and different type of graph switched on at the beginning.

We found this type of activity to be very suitable for the chosen approach – experiential learning.



Fig 6: Redrawing task

The workbook consists of nine sections:

- 1. *Before we start* installation guide, instructions on how to work with programs, to suppress fear of making mistakes we stressed the aim of the project to improve understanding, not to evaluate students' knowledge
- 2. *Spherical coordinates* we suppose basic knowledge of spherical coordinates but ask students to solve some simple tasks to familiarize with them further (supported by 3d_line tool)
- 3. *Wave functions of hydrogen atom eigenstates* theoretical section remembering of coordinates' separation in the wave function and the role of quantum numbers
- 4. Legendre polynomials through using program Legendre_2D, students should understand and get used to different types of graphs in which the functions of coordinate \mathcal{G} can be drawn
- 5. Spherical harmonics in this section students build up their spatial image of the Legendre polynomials' square (using program Legendre_3D)
- 6. *Radial part* students combine angular and radial parts together and draw probability density graphs (using 3D_obitals tool), at the end of this section is an explanation of difference between radial probability density and radial part of the probability density
- Orbitals firstly students describe their view of orbital, then the explanation and warning about common textbook mistakes follows
 Solutions
- 9. *Questionnaire* we asked students about their opinion on the whole project

Another example of student's solution is on the fig. 7. The student drew each bottom plot (combination of angular and radial part of probability density) according to the above ones (angular and radial part displayed separately) that were displayed by computer.



Fig 7: Combination of angular and radial part (part of student's workbook)

The tasks were designed according to the principles of experiential learning (to be specific, according to the *Kolb's learning cycle*) (Luckner & Nadler 1997). Each section of the workbook follows the same pattern described below. Kolb's stages are indicated in the brackets.

- Firstly, students are asked to play with each program and build up their own hypotheses (on the basis of previous knowledge) of what the programs draw. (*Concrete experience*) This part also deals with their tendency to play and enjoy the nice pictures before they start serious work.
- As the second step the students confront their hypotheses with explanation offered in their worksheet. (*Reflective observation*)
- Then they are asked to "prepare a plan" how to redraw one type of graph to other types or how to build 3D plot from planar cut. (*Abstract conceptualization*)
- In the final step they use their "plan" and solve "redrawing" tasks, or other tasks. (*Active experimentation* with new *concrete experience*) They check their answers immediately. This enables them to correct the tasks as well as their solving methods. (*Reflective observation*)
- In the end of each section they should write down the pros and cons of the different ways in which the functions can be illustrated. (*Reflective observation*)

3. Project design

The whole project was designed for *university students* (the 2nd year, future physics teachers) as a part of their compulsory introductory quantum mechanic course. Each student received a copy of the workbook that contains everything necessary (as installation instructions, tasks,

results, explanations ...). Software was available on the internet or on a CD. They solved the tasks as homework (or they could work it up in school computer laboratory). After that we collected the filled-in workbooks, made notes to their answers, gave them back to students and discussed their answers (in small groups outside the regular class) as well as their opinions about project.

We decided to do this as homework, not during a lesson (in fact the homework substituted a lesson which was cancelled) because of the following reasons:

- Students can work on their own pace (it is crucial in the experimentation phase) and return to previous parts if they needed.
- Working without a teacher needs a very precise and detailed workbook, but minimizes fear of making mistakes. Students could of course ask a tutor (personally or via email) for help in case of any problem during the project.
- It would have been difficult to find enough computers for all students working at one time and not disturbing others.

Outcomes: Students' opinions

After collecting the workbooks we summarized outcomes from the piloting of this project (summer term 2006). We received 10 completely filled-in workbooks in total.

1. Comparison of different visualization methods

We asked the students to compare different types of graphs which were used in the tools. Here we summarize their answers in the following two tables.

Because different students mentioned various pros and cons of all used types of graphs, we concluded that it was useful to show the same function in different types of graphs. Different aspects are better visible in different graphs and students can build their view according to all of the graphs.

2. Students' feeling about the project

In the last section of the workbook and in the discussion after solving it, we asked students to express their feelings about their work and opinions on the whole project. All of the students found it interesting and attractive, more like a game than study, one student wrote in the final questionnaire: "... it was like an amusing detective story whether my ideas or pictures were correct."

They liked the very vivid presentation of such an abstract topic. Some of them wrote that the "redrawing" task improved their understanding ("...when I had to draw pictures, I realized that I did not understand the explanation well and needed to read it again", "before working with these tools I was not able to imagine what does it mean: 'orbital like sphere inside another sphere'"). Generally they appreciated recapitulation of the

spherical coordinates at the beginning and found the sequence of sections good.

The only negative factor they mentioned was the long time they spent with solving the tasks (approx. 4-5 hours, twice more than we expected). Despite it they felt that it was not waste time and appreciated the possibility to arrange time individually.

According to students' feedback it may be said that the work did amuse them. The results of their work show that their understanding of the topic has improved while working on the tasks. On the other hand, we realized some processing difficulties (timing, better after- discussion arrangement ...) which should be solved.

Future plans: What next?

The project outcomes gave us feeling that this way is suitable. So, we have continued in improving the current computer tools and tasks and developing new ones. There are some of our goals which are in progress now.

Web support

We are creating an appropriate web presentation to make the materials available to teachers willing to use these tools and methods. To make them more easy-to-use, we are dividing the project into smaller parts which can be used independently.

Widening the target group

The activities and programs were aimed at university students. However, some basic parts of quantum mechanics are part of high school curricula. Middle school students (and even teachers) often lack the imagination of orbitals. We are therefore transforming some tasks to this level and preparing a suitable way how to use these tools in the middle school.

Extending the topic

We would like to continue the development of programs and activities and cover the topic further. Some of the ideas are:

- to add radial density of probability to the graphs and create an activity that would help students to understand the difference between density of probability at a given radius and the radial density
- to make a program enabling students to create and observe combinations of stationary states (real combinations, hybridization) and make a few steps towards quantum theory of chemical bond

• to show the time development of combined states and orbitals However, these goals demand further study and maybe even the change of platform (use of Mathematica or Java instead of LabVIEW). Graphs of angular density of probability

XY Graph



+ a kind of graph well known to students

 not connected to spatial distribution of probability density

Intensity Graph

+ a good visualization of spatial dependence



+ the illusive limitation by radius doesn't occur as in the polar graphs

+ it is clear that the radius can be extended and the value would be the same, breaks the common misinterpretation of polar graphs of angular functions

- difficult to read function values

+ it is possible to read values

Polar Graph

+ easy to remember



- more difficult to understand correctly than other graphs

 leads to misinterpretation in terms of illusive limitation of probability density by radius (note: Sometimes these images are wrongly interpreted as probability density plots!)



3D Polar Graph

- + nicer than 2D, more attractive
- it is difficult to read function values



Sphere

- + gives better view than flat graphs
- impossible to read function values

Graphs of probability density

Planar Cut



+ offers good view on distribution of probability density in space

+/- really illustrative but one has to be aware how to create the spatial image and that this is only a cut

Spherical Cut

+ good to study dependence of probability density on distance



- the influence of radial part is not vivid

+/– isn't of much use when alone but good in connection with other graphs (mainly the XY graph of radial part of wave function)

Conclusion

It is quite easy to find various tools for visualizing different parts of the atomic wave functions, probability densities etc. on the internet. However, most of these sites contain tools that can only be used for visualization. Even after a long search we did not find anything more complex that would lead students to deeper understanding, accompanied by methodics or hints for teachers.

In this aspect and mostly in the emphasis on students' active work is our project innovative and, according to the response from our students, even successful. Even though students subjectively appreciated the project, the real influence on their understanding and knowledge of the hydrogen atom orbitals has not been tested yet and will be a part of further research. If you are interested, you can find all materials on the following address:

http://kdf.mff.cuni.cz/~broklova/orbitals/

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Learning about Waves and Sound

Hear-and-See Tool for Learning Basic Acoustics

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Abstract

Learning concepts related to specific phenomena becomes easier and more effective when learners are allowed to experiment them with their own senses. In acoustics, basic phenomena can be perceived by hearing, although sight is also involved through images and text.

Therefore, a learning tool which involves also the sense of hearing should be welcomed, especially if it is easy to implement. The hearand-see tool presented here is based on the open-source audio software Audacity. It could be also implemented with similar programs such as WaveLab or Adobe Audition, both of which are commercially available. Nevertheless, the fact that Audacity is available on the web, free of charge, makes it an ideal choice for implementing this hearand-see tool, even as a sort of home lab.

Many learning activities can be devised using this software application with headphones and a microphone. Several existing examples are described here: an activity designed to observe how a plain sound of defined pitch consists of a periodic variation in air pressure which is recorded through the microphone as a periodic electrical signal; another that allows the learner to quantify the differences among his or her vowel sounds looking at the corresponding frequency spectra; and another that can be used to investigate the differences between sound and noise, or the differences in the fundamental frequencies between musical notes that differ by an octave.

1. Introduction

In a previous paper (Novell, 2004), one of the authors reported on the constructivist approach fostered by hear-and-see tools as another way of incorporating information technologies into science education in the form of computer-based education (CBE).

Indeed, learning concepts related to specific phenomena becomes easier and more effective when learners are allowed to experiment them with their own senses. In acoustics, basic phenomena can be perceived by hearing, although sight is also involved through images and text.

Therefore, a learning tool which involves also the sense of hearing should be welcomed, especially if it is easy to implement.

2. Hear-and-see tools in CBE-environments

Novell (2004) also analyzed the way of implementing a hear-and-see tool as a multimedia unit of definite structure and the constructivist model of learning behind this tool.

In this context, the keyword "multimedia" must be understood in terms of the 3rd. possible definition given by Guttormsen Schär and Krueger (2000), as a modality of communication or multisensory (e.g. visual, auditory, olfactory) interaction. This modality of communication allows a representation according to a cognitive model based on a combination of visual and auditory information with less cognitive load. Overload on one sense causes tiredness and reduced attention, whereas a balance between visual and auditory information reduces the cognitive load.

In a general way, CBE must be in some way more useful than traditional teaching methods, as stated by Karjalainen and Rahkila (1995, 1998). Therefore, the starting point for every CBE project is to ask if CBE can give "something extra" or "a better way" in the means of education compared to traditional methods. These papers describe the "QuickSig" environment, which is a good example of an environment that offers many possibilities for implementing hear-and-see tools. The authors reported on several CBE-applications in the form of courses, encompassing topics such as perception of pitch, loudness, timbre and duration, masking, and critical band.

Other hear-and-see tools have been implemented by Arai (2002, 2003) in the form of computer-based tools for teaching phonetics. These are software tools for analysis and resynthesis of speech sounds. These papers point out the usefulness of hear-and-see tools for teaching acoustics not only to technical students, but also to students majoring in fields such as linguistics, psychology and speech pathology. Moreover, the tools are applicable to a range of learner ages and academic levels, since they enable students to grasp contents in acoustics more intuitively.

As much of the practical work in digital signal processing is now done using computers anyway, it is only natural to apply CBE to teaching, as well. Furthermore, the issue here is sound, and the best way to teach sound is to use sound.

3. Hear-and-see tool based on Audacity

Based on the idea reported in a previous paper by one of the authors (Novell, 2004), an arrangement was created consisting of the Audacity application, the Internet and simple computer equipment including headphones and PC microphones.

Audacity is an open-source sound processor which allows easy implementation of a powerful hear-and-see tool. Whilst similar, commercially available programs such as WaveLab or Adobe Audition could also be used, the fact that Audacity is available on the web, free of charge, makes it an ideal choice for implementing this hear-and-see tool, even as a sort of home lab, where the student can perform real laboratory experiments as a remote learning activity.

There are many similarities between the aforementioned audio processors. Therefore, for this one case, the idea stated by Karjalainen and Rahkila (1995) that the emphasis of a CBE-application should always be on the subject, not on the application itself, does not apply fully: one of the objectives of the activity with our hear-and-see tool was to familiarize the students with the use of standard audio processors.

Figure 1 shows the upper, most relevant part of the Audacity environment with a sound sample and the main command buttons. The most important buttons for our purposes are No. 1 to 6 (playback, stop, etc.) and No. 11 (source selection between microphone and pre-recorded file). Screen elements nos. 16 to 20 are also very useful to reach the best display and for a better reading of data (Nr. 14, amplitude; No. 15, time).



Figure 1. Buttons and handling elements of Audacity.

4. Activities on acoustics already implemented with the proposed hear-and-see tool

In the following section, we describe some learning activities which have been already implemented using our Audacity-based hear-and-see tool.

4.1. Timbre, waveform and acoustic spectrum

The aim of this activity was to observe the difference in waveforms and acoustic spectrums of different timbres. After installing Audacity, the student had to record his or her own speech (in mono) pronouncing the Catalan word "universitat" (pronounced



*Figure 2: Waveform for the word "universitat" (pronounced /*_uni_bersi'tAt/) *as recorded with Audacity.*

/uni,bersi't^t/) which

has different vowels,

including a repeated one ("i"). Beforehand, students had seen in the theoretical explanation that timber differentiates also the different vowels.

Figure 2 shows the waveform of the recorded sample in the Audacity screen; the vertical line, moving from left to right, shows the exact place of the waveform being played back at each moment. The white labels with text have been added by the authors, to show what the student hears in the playback.



Figure 3: Waveform for the vowel "u" [/u/], after selection and enlargement from the previous Figure 2.

Figure 4: Acoustic spectrum for the waveform of the previous Figure 3, as obtained with Audacity.

After identifying the portion of the waveform corresponding to a given pure vowel, for example the Spanish or Catalan "u" [/u/], the student could enlarge the display in order to observe the waveform in detail and its differences with other vowels (Figure 3).

Then the student had to select the proper portion of waveform, call the function "Plot spectrum" in the View menu, and see the acoustic

spectrum obtained. In our implementation, students were encouraged to "play" with the different parameters of the FFT function offered by Audacity (essentially, analysis block size and smoothing window), especially in order to obtain the clearest display of the different harmonics in the spectrum. In our example, Figure 4 shows the spectrum of the displayed waveform (portion of frequencies up to ca. 11 kHz) with an analysis block size of 1024 and a Hanning smoothing window.

The student had to use a spreadsheet to compare the frequencies of the different overtones (at least the first 8 or 10) and their intensity levels. The aim was a quantitative characterization of the spectral differences between two different vowels and the similarity between identical vowels (e.g. the two "i"s in our example).

4.2. Difference between sound an noise

The procedure described allows also to investigate the differences between sound and noise. Here, the term 'sound' is understood to be any sound of definite pitch, such as vowels in our speech, or a typically clear sound of musical instruments of definite pitch (most string, wood and brass instruments, for example), when they are played skillfully. In contrast, a 'noise' is understood here to be a sound that has no definite pitch, i.e. a continuous spectrum or a series of overtones which do not form any series of harmonics. The students themselves could experiment with any typical noise, for example that of traffic, and observe the lack of pattern repetition in the waveform, as well as the absence of relevant overtones or the lack of a series of harmonics. Figures 5 and 6 show the images for the hissing noise produced when a long "s" is pronounced, obtained in the same way as in Figures 3 and 4, respectively.



Figure 5. Waveform for a hissing noise (long "s").

Figure 6: Acoustic spectrum for the waveform of Figure 5.

4.3. Pitch and fundamental frequency

The starting point was a music sample played on a saxophone (Figure 7), including the deepest and the highest note that can be played on this instrument (in musical notation: D_{3}^{\prime} and A_{5}^{\prime} , respectively, where the sub index indicates the octave) and a two-octave ascendant and descendent scale of E_{3}^{\prime} major, where the musical notes E_{3}^{\prime} (at octave distances) could easily be recognized by hearing, even by students with no musical training at all. Using the aforementioned procedure, the student had to identify the portion of the waveform corresponding to the deepest sound, the highest sound, and the three notes at octave distances. He or she was then asked to calculate the respective periods and fundamental frequencies directly using the time scale of the waveform displayed. The value calculated for the fundamental frequency had to be then checked against the value taken from the spectrum obtained as before.



In this way, the student could deduce the main relationship between pitch and fundamental frequency, and calculate the relationship between fundamental frequencies for sounds differing by one or more octaves.

5. Student response to this hear-and-see tool

The activities described in the preceding section were implemented within the framework of an elective subject on acoustics as a first pilot study with only nine students. Although this number did not allow us to draw any firm conclusions yet, we were able to observe (by means of a questionnaire) some meaningful facts, which we will continue to examine in future semesters with a greater number of students.

Almost all the students agreed that the activities described helped them to understand the contents of the subject better. Opinions were divided into approximately two equal groups regarding the degree of difficulty of the activities. An explanation is that this elective subject was chosen by students on different engineering degrees, ranging from telecommunications engineering to chemical engineering. Whereas the telecommunications or electronics engineering students managed quite well with the Audacity environment and the topics of acoustics, the chemical engineering students had evident difficulties both with the hearand-see tool and the acoustics content. Nonetheless, also these students recognized that the activities had been useful for learning something new and, additionally, in an entertaining way.

6. Conclusions

The open-source sound processor Audacity was used as a free and yet powerful hear-and-see tool, which allows the relatively easy implementation of a series of activities on acoustics.

We have presented in detail an initial series of successfully implemented activities. They can be extended to other aspects of acoustics, for example the (psychophysical) Weber and Fechner's law and the decibel scale, frequency response of the human ear, synthesis of beats, etc.

Since these activities were carried out by the students in their own homes, this hear-and-see tool can also serve as a sort of home laboratory, which allows the students to experiment freely for themselves. And this is also "something extra" compared to traditional methods.

Acknowledgements

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Learning Astronomy

Project based Astrophysics with Role Playing

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Abstract

A teaching sequence in astrophysics for future science teachers that incorporates both explicit discussions of the nature of scientific models and the role of these models in explanations has been developed and tested. The goal was to promote meaningful learning in Physics. The lectures were combined with lab and project work. During the lectures the students formed groups in the classroom, thus enhancing discussions. A semi-structured role-play was used to report on the project. The students impersonated different experts, with different perspective of the phenomenon. The students expanded on the descriptions of the roles in their own way in their group work, thus adding theoretical perspectives of the phenomenon at hand – stellar birth, life and death. The teaching was well received by the students and we found that it elicited meaningful learning.

Introduction

A prerequisite for the teaching of physics is that the teacher realizes the importance of theoretical models in Physics, and their role in the interplay between Physics and the real world (Coll, France & Taylor, 2005; Crawford & Cullin, 2004; Justi, & van Driel, 2005). We believe that a teaching sequence that incorporates both explicit discussions of the nature of models and their role in explanations of phenomena can be very successful. The goal of such teaching is to provide opportunity for meaningful learning of physical phenomena (Viennot, 2003). Hence, meaningful learning is taken to mean the ability to distinguish between the world of models and the real world (Giere, 1997), the recognition of the limitations of models, and the coexistence of several theoretical models for a given phenomenon. It is crucial that students are given the opportunity to work with several different models for a given phenomenon. This will make it possible for students to discern that there is more than one model to use, which is acceptable within Physics. The consequences of variation theory (Marton & Booth, 1997) for teaching are developed by Marton, Runesson and Tsui (2004). Our teaching sequence builds on both variation of the learning object and that learning in physics can be seen as the acquisition of more and more explanatory models for a given phenomenon. Thornton (1995), Taber (1998) and Redfors & Ryder (2001) all find that students use several different mental models when they talk about real world phenomena. We

think that to understand something is to be able to explain it and the mental models used in explanations are conjured up – depending on the context – as the explanation starts. Thus, use of mental models in explanations is often context dependent (Redfors & Ryder, 2001).

The teaching sequence

We have developed and implemented a research based teaching sequence in an advanced course in astrophysics. The author was the teacher and it was a student centered approach. The course was a part of the Swedish secondary science teacher program. The program takes $4\frac{1}{2}$ years and comprises subject theory, teaching and learning theory and practice teaching (Redfors & Eskilsson, 2003). In the second to last semester the students take elective science courses and one of their choices was this course in astrophysics. It was a 5 week course and there were two teachers involved. The author was teaching the second part of the course, which is focused here. It was mathematically the most advanced course for the student teachers in their education. Therefore, the teaching was structured to encourage student and group activity and it was designed to promote qualitative thinking rather then mathematical problem solving. The aim was for the students to be able to use the mathematically formulated models from the first part of the course in qualitative explanations and discussions. The teaching sequence was partially based on contrastive teaching (Schecker & Niedderer, 1996) and it consisted of interactive lectures and lab-work, and alongside these, the students worked in groups with a project.

The lectures

The lectures were not traditional instead we worked according to the following principle. The students were divided into groups, and they were sitting with their group in the classroom. To have the students sit with their group members augments discussions in the class (Mazur, 1997). It is also quick and convenient to change between group and full class activities. The groups were used during lectures and in the project work. A typical lecture would start with the teacher giving an introduction to the material. The introduction served as an *advance organizer* (Novak, 1998) for the students who thereafter discussed and prepared the rest of the lecture in their groups. The advance organizer was in this case a general description of the content of the chapter, which was set in the astrophysical framework of the course. The students were given the opportunity to make connections between the new material and their previous knowledge, especially from earlier parts of the course. The advance organizer also helped them to see the logical structure of the content in the chapter. After this initial part of the lecture the content was divided up and given to the groups who were given time to discuss their part. The teacher was circling in the room as a resource for the groups. Taking part in discussions and challenging student ideas. The lecture

continued with the student groups lecturing their part of the content for the rest of the class. Hence, the students themselves had to discuss all details, and they were helped to keep their presentations linked to the introduction of the teacher, thus giving the overall lecture a logical structure and making the introduction a true *advance organizer*. These sessions led by students were profitable for both lecturing and listening students. The lecture was concluded by a general discussion generating questions that were kept unanswered for contemplation until the next lecture.

The lab-work

The teaching sequence also contained lab-work. It was a semi-structured task. They worked with simulated observations of stellar spectra, and were asked to establish ways to categorize the different stars of an open cluster according to spectral classes. The students worked in pairs during this lab, thus they had mostly different companions compared to lectures and project. In the instruction sheet we had inserted open questions that the two students should discuss as they worked with the analysis. The questions were situated in the lab-context.

Role playing

Drama in science education can be of different sorts Ødegaard (2003) discusses this in an article on drama in upper secondary school. It can be impulsive, conjured in a moment, i.e. students are improvising. Drama can also be structured, based on a manuscript, or it can be something in between, semi-structured.

We have developed a semi-structured role playing scenario primarily focusing on the first two perspectives mentioned above. We have focused on the role of astrophysical models and in doing so the first two perspectives come to dominate. We have elaborated on an existing structure described elsewhere (Francis, 2005; Francis & Byrne, 1999) in the group based project. The students were given short descriptions of the knowledge of different experts, required to understand the process of star formation. They were asked to extend these descriptions in their preferred direction. The task given to the student was formulated like this.

There are many giant gas clouds in space. They have diameters of about 10^{16} m, and masses of around 3×10^{30} kg. They contain chemical elements needed to form a sun and its planets. Your task is to figure out how a star with a planetary system can develop from these clouds. Below there are the opinions of nine experts described in short. Your group will elaborate on them and make comprehensive descriptions of the experts. Based on these your group will write the "star and planetary system formation" story and submit. Remember to relate your story to observational evidence of today.

Your group will submit one story. However, on your oral exam

you will individually act in the role playing and I will decide who plays which role. You will be expected to show that you have acquired expertise in all nine areas.

All the experts included are needed to understand and explain the complex phenomenon of star formation, i.e. there were experts on condensation, observations, gravitation, meteorites, planets, stones and minerals, rotation, stars and stellar evolution.

Hence, it was a semi-structured drama, but the students were given the opportunity to develop the descriptions of the roles in any direction they chose, thus an ownership developed that stimulated the learning process. They submitted their extended role descriptions in the form of a complete story in writing, group by group.

Examination

The basis for the examination of the second part of the course was the student performance during lectures and lab-work. The written material was the lab-reports and the report of the project. The final examination was the oral role-playing, where the students played several different roles. The students were evaluated normatively against correct scientific arguments based on the role character perspective.

Results

The teaching sequence was evaluated through teacher observations, written questionnaires to the students and group discussions.

The lectures

The teacher (the author) made notes after each lecture. The most noteworthy observation was how the students "came alive" when they got the chance to take charge of the teaching and prepared the remaining part of the lecture. They based their work on the information given at the start of the lecture, and on information from previous parts of the course. They read the material and worked to make a comprehensive presentation, including the new material. Their preparatory work, including discussions in the group, seemed fruitful for their learning.

The students enjoyed the teaching sequence and they highlighted the importance of following the course literature closely, since it was difficult to read. They appreciated the discussions in the groups during the lectures, and deemed them to be fruitful. They concluded that discussions with peers, with supervision, were good learning opportunities.

The lab-work

The lab was found interesting and stimulating for the students. They got insights into the work of classifying that astronomers do. Some said it brought interesting questions to focus and that it was a useful part of their learning experience. Also here the role of supervisor was fruitful with frequent opportunities to challenge the student pairs and help them with additional questions.

The role-playing project

The project work was really appreciated and it was considered by the students to give a nice overview of the course content, at the same time as it was an application of the newly learnt material. Furthermore they appreciated that it was not strongly controlled. It worked to increase interest and it helped to put new knowledge into context. They thought the examination through role-playing was an interesting experience and they considered it to be a good learning opportunity. Finally they were a bit surprised that we had been able to work this way in an advanced course.

Discussion

To be able to discuss with peers in groups has in several cases been found fruitful for learning, e.g. Mazur (1997). For us, group discussions were central and the students were forced to engage with the new theory and make sense of it together. Especially, when they were asked to restructure the material and present it to the other groups during the lectures. It seems that student learning really was improved by the project work they all did alongside the lectures and labs. An ongoing project like this where students get to engage and expand into areas chosen by them was effective (Schecker & Niedderer, 1996; Novak, 1998). The project becomes a direct application and it trains students to use new knowledge in new contexts. We conclude that there are good reasons for students to be given the opportunity to discuss in groups and challenge peer ideas in a project. The project needs to be closely interrelated with the course content and use of the new theory presented in the course should be required. Also of importance is that students get to define or expand on the project tasks themselves.

The role-playing as an examination was really interesting and it was possible to distinguish different performances. We could evaluate individually and grade students accordingly. The students appreciated this kind of examination and they considered it to be a valuable learning opportunity. Hence, we are in agreement with Ödegaard (2003) in finding role-playing interesting and we see a lot of possibilities to expand the use of it in higher education.

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Teaching future teachers basic astronomy concepts

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Abstract

We conducted a series of constructivist activities with future elementary and junior high school teachers aimed at changing their conceptions about the Sun-Earth-Moon relative movements like Moon phases, Sun and Moon eclipses, and others. Students' astronomy conceptions, at the beginning and at the end of the study, were analyzed by means of a written questionnaire containing 21 items. Most activities were performed in class, followed by a group discussion guided by the teacher; some activities were assigned as homework. In the pos-test questionnaire, only the experimental class and one of the control groups showed a statistically significant improvement, with the experimental class making the most impressive progress.

Introduction

High school, college, and university students' notions of astronomy concepts have been investigated far less than those of elementary school students, which have been researched extensively during the last thirty years. Lightman and Sadler (1993) found that high school students shared some of the elementary school children's conceptions. Zeilik et al. (1998) obtained similar results among university majors.

Trumper (2001) assessed students' basic astronomy conceptions from junior high school through university. He summarized the most widespread misconceptions at all educational levels (see Table 1) and found that future elementary school teachers got the lowest correct response rate (32%), even lower than that scored by junior high school students (36%). This suggests that future elementary teachers have more alternative conceptions about basic astronomy concepts than typical junior high school students.

Methods

Bearing in mind the results of the foregoing studies, we examined future teachers' alternative conceptions and created a series of constructivist activities to change future teachers' conceptions about the Sun-Earth-Moon relative movements like Moon phases, Sun and Moon eclipses, and more.

Subject	Misconception	Junior high school	Senior high school	Future primary teachers	Future high school teachers	Non- science university
Day- night cycle	Earth moves around the sun	36	30	51	37	34
<u>Moon's</u> phases	Moon moves into earth's shadow	19	27	16	25	29
	Moon moves into sun's shadow	25	17	29	23	16
Reason for seasons	Earth closer to sun in summer	45	33	37	32	32
Reason for it being hotter in summer than in winter	Earth closer to sun in summer	36	28	20	19	22
	Earth's rotational axis flips back and forth	20	23	31	29	23
Sun overhead at noon	Everyday	35	36	48	44	42
<u>Moon's</u> phase in solar eclipse	Full phase	74	77	71	75	70
<u>Moon's</u> <u>rotation –</u> <u>same side</u> <u>visible</u>	Moon does not rotate on its axis	54	57	51	47	50

Table 1: Most widespread astronomy misconceptions by groups, in percentages

The research encompassed 138 university and college students studying introductory courses on astronomy for the first time. The experimental class comprised 19 technology teachers at junior high school taking a semester course in their retraining for science teaching in primary and junior high schools at an academic college of education. There were three control classes following a traditional lecture format. One comprised 83 university students taking a semester course in the Interdisciplinary Department of the Faculty of Humanities. Another was 14 future high school physics teachers taking a semester in the Physics-Mathematics Teaching Department of the Faculty of Science and Science Education in the same university. The third one was made up of 22 future primary school teachers taking a yearlong course in their training for science teaching in Bedouin primary schools at the same academic college of education as the experimental class.

Students' astronomy conceptions were analyzed by means of a written questionnaire containing 21 items presented at the beginning of the course¹⁷.

Results

Pre-test results

Figure 1 shows the scores obtained by the different groups in answering the whole questionnaire, and the questions about phenomena related to Sun-Earth-Moon relative motions, at the beginning of their introductory astronomy course.

In the whole questionnaire, there was a statistically significant difference between the success of the university students and of all the other groups with the largest effect size (Cohen, 1988) for the future Bedouin primary school teachers, as can be seen in Table 2, and for questions related to



Fig 1. Correct answers percentage of the different groups in the pre-test.

Sun-Earth-Moon relative motions we found a statistically significant difference only between the university students and the future Bedouin primary school teachers (t = 2.04, <u>p</u>-value = .05, Cohen's effect size – d = .77).

¹⁷ For a complete version of the questionnaire, see Trumper (November 2006), Teaching future teachers basic astronomy concepts – seasonal changes – at a time of reform in science education. <u>Journal of Research in Science Teaching</u>, in press.

	Students' success	t - test	<u>p</u> -value	Cohen's effect size - d
University students	35.1	-	-	-
Future physics teachers	27.2	1.862	.004	.488
Future primary school teachers (Bedouins)	21.8	4.048	< .001	.872
Experimental class	24.8	3.048	.002	.684

Table 2: Statistically significant difference between the university students and all the other groups in the whole questionnaire (pre-test)

Experimental Instructional Activities and Findings

Most activities were performed in class, followed by a group discussion guided by the teacher; some activities were assigned as homework. At the beginning, students performed an activity concerning the day and night change in the spinning Earth, from sunrise to midnight. The light from an overhead projector represented sunlight and the student's head the spinning Earth. Students were asked to look to the right side at the beginning (sunrise) and then to turn counterclockwise and to mark the position of their eyes in each of the situations. Fifteen students marked all the positions correctly, three students forgot to mark the position of their eves at midnight, and one student marked midnight as if it was noon. On the same day, the students were assigned a homework activity: They were asked to *predict the Moon phases* during the Hebrew (or Muslim) month, beginning with the New Moon. They had to arrange the pictures seen in Figure 2 on the appropriate squares of Figure 3, writing down the names of the Moon phases according to the Table 3. Students were asked to watch the Moon phases every night during the next two weeks, to compare their observation with their initial prediction, and to correct it if necessary.

Ten students predicted correctly the order of the Moon phases after watching them for two weeks, and nine students made a wrong prediction.

Afterwards, the students performed an activity intended *to simulate the Moon phases as seen from Earth*. Students stood in front of an overhead projector representing sunlight. Their heads represented the Earth, and they held a Styrofoam ball with a large wooden stick slightly above their heads, representing the Moon.

Age of the Moon (in days)	Phase name		
1	New Moon		
2-7	Waxing Crescent		
8	First quarter		
9-14	Waxing Gibbous		
15	Full Moon		
16-22	Waning Gibbous		
23	Third quarter		
24-29	Waning Crescent		

Table 3: Names of Moon's phases during a month

Students had to stand in front of the light and stretch their right arm holding the "Moon" towards the "Sun". Then they had to move counterclockwise and watch how the illuminated part of the "Moon" changed shape. After completing a whole turn they had to draw the successive phases of the Moon, to compare them with their predictions, and to answer several questions related to the activity, including their causal explanations of the Moon phases: Twelve students gave a correct, or almost correct, answer, such as: "The changing angle between the Moon and the Earth", "The Moon's revolution around the Earth and the changing angle between the Sun and the Moon relative to the Earth", "The position of the Moon in its revolution around the Earth during a period of thirty days, according to the light coming up from the Sun", "The angle between the Earth and the Moon changes in relation to the Sun's light", "The Moon revolves around the Earth, so every night it is positioned at a different angle", "The changing angle between the Earth and the Moon, and then the amount of light reflected to us changes". Five students wrote only "The Moon's revolution around the Earth", and two wrote "The periodicity of thirty days of the Moon phases". A week after, the students performed a group activity intended to demonstrate that the Moon rotates on its axis once a month, always showing us the same side. One student held the "Moon" in his hand (a Styrofoam ball with a wooden stick on the top and a Bristol paper flag on it). The other students sat down in the middle of the classroom, representing observers on the "Earth", and the student with the "Moon" had to revolve around them showing the same face of the "Moon" during the whole turn. After several tries he succeeded, and the students had to reach a conclusion about the Moon's rotation. Next the student with the "Moon" was asked to turn around the "Earth" without rotating the "Moon", and to complete the rotation of the "Moon" around its axis in less (and in more) than a month in order to confirm the students'

conclusion. All the students reached the right conclusion that the Moon rotates around its axis once a month, the same time it takes the Moon to complete a revolution around the Earth.



Fig. 2: Moon phases arranged randomly



Fig. 3: Paper sheet for the arrangement of students' Moon phases prediction

Several weeks after, students performed their last activity in pairs, in order to simulate *Moon and Sun eclipses*, using the same "Sun", the same "Moon", and the same "Earth" as in activity of the Moon phases. They

were given a simple explanation about eclipses and were asked: (a) what has to be the relative Sun-Earth-Moon position in a Moon and Sun eclipse: seven students answered that they have to be in the same plane, six answered that the angle between the Sun, the Moon, and the Earth has to be 180°, and three students answered that they have to be positioned in the same straight line, and (b) what is the Moon phase during a Moon (Sun) eclipse: Fourteen students answered that the Moon is in its Full (New) phase, and four students answered that it happens in the middle (at the beginning or end) of the month.

Post-Test Results

The post-test (the same as the pre-test) was presented to the experimental class and to the control groups on their examination day. Figure 4 shows the extent of success of the different groups in answering the whole questionnaire, and the questions about phenomena related to the Sun-Earth-Moon relative motions.



Fig. 4: Correct answers percentage of the different groups in the post-test.

In the whole questionnaire, we found a statistically significant improvement in all the groups with the largest effect size for the experimental class as can be seen in Table 4. For the Sun-Earth-Moon relative motions' questions we found a statistically significant difference only for the future Bedouin primary school teachers (t = 5.64, p-value < .01, Cohen's d = 1.81) and for the experimental class (t = 9.89, p-value < .01, Cohen's d = 3.34). The significant improvement in the future Bedouin teachers' conceptions may be explained by their very low scores in the pre-test and by the fact that they were the only group having an annual course. Nevertheless, the experimental class showed the most

	Pre-test total success	Post-test total success	t	<u>p</u> -value	Cohen's effect size - d
University students	35.1	42.5	2.003	.025	.37
Future physics teachers	27.2	40.9	2.222	.023	.95
Future Bedouin primary school teachers	21.8	36.8	4.607	< .001	1.63
Experimental class	24.8	67.0	10.19	< .001	4.20

impressive improvement with a very large normalized gain of g = 0.8 (Hake, 2002) and the greatest effect size.

Table 4: Comparison of the total success in the pre- and post-test for all the groups

Conclusions

Understanding the solar system involves a number of related conceptual areas that are clearly of importance in relation to students' existing conceptions and are difficult to explain since they do not match their daily observations. They include a perception of spatial aspects of the Earth, a conception of day and night, of seasonal change, etc., which include compound movements of the Moon, the Sun, and the stars. In this study, we can see clearly that many students are not post-Copernican in their notions of planet Earth in space, and hold alternative notions to the accepted scientific concept in various basic astronomy subjects. Students in the experimental class conducted both individual activities at home and in the classroom; the paired and group activities were conducted in the classroom. They also participated in guided discussions, arguing about their different notions and continuously assessing their significance, and checking their validity. The students were active constructors of their own knowledge, while the process of knowledge acquisition was greatly assisted by interactions with peers and in particular, with the teacher.

The findings of this study show that both the experimental class and the control groups improved their basic astronomy concepts in a statistically significant way. Moreover, regarding the subjects relevant to this study only the future Bedouin primary school teachers and the experimental class showed a statistically significant improvement. In both cases, the experimental class made the most impressive improvement of all.
These findings support the constructivist approach in teaching, in which students are confronted with their alternative conceptions in a conceptually centered learning environment that actively engages them.

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Teaching Physics Concepts

Year 12 Students' Mental Models of the Nature of Light

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Abstract

This paper reports on the third year of a three-year longitudinal investigation into six Year 10 secondary students' understanding of optics at a secondary school level. During the first two years of the study the students' understanding of geometrical optics was explored with the adoption of constructivist teaching and learning strategies. The students' understanding of geometrical optics following the Year 11 teaching stage then formed the basis of exploration of their mental models of the nature of light. This exploration occurred before, during, and following a Year 12 teaching stage where the students studied physical optics and quantum ideas. Before the Year 12 teaching stage the students had constructed mental models of light that related to their understanding of a ray. Over the Year 12 teaching stage the students' mental models changed to conceptualizations of a photon. There was evidence in the students' mental models of a hybridization of the particle and wave scientific models. That is, they conceptualized the photon as having both wave and particle characteristics. The variation in the students' hybrid models also suggested a variation in the way they conceived of the nature of scientific models.

Introduction

The models of science are representations of objects, events, ideas, systems or processes (Gilbert, 1995). Scientific models are one of the main products of science (Gilbert, 1994; Halloum, 1996) and play a crucial role in reducing the complexity of phenomena by allowing a more visual reproduction of abstract theories so that predictions of behavior can be made and tested (Gilbert, 1995). Scientific models help individuals conceptualize reality and serve as a bridge between the mind and the material world. For example, in conceptualizing the behavior of light secondary school students study two scientific models, referred to as the wave and particle models.

In interacting with the environment individuals construct mental models that are interpreted and understood in relation to existing mental models. The constructed mental models provide the individual with predictive and explanatory powers for understanding the interaction (Driver, 1995; Norman, 1983). Mental models are mental representations which individuals generate during cognitive functioning and have structures that correspond to, but do not directly represent, a structure in reality (Johnson-Laird, 1983; Vosniadou, 1994). Therefore, before studying the scientific models of light secondary school students will have constructed mental models of light, which may have some impact on their understandings of the scientific models. The purpose of this study was to investigate the impact on students' mental models of light as a result of a teaching sequence where the students studied the particle and wave models of light.

This paper reports on one aspect of the third year of a longitudinal case study of six Year 10 students' understanding of optics with the adoption of a constructivist teaching and learning strategies in three separate teaching stages over a three-year period. This aspect relates to an investigation of the students' mental models of the nature of light during their 12th year of schooling. The researcher acted in the dual roles of teacher and researcher. The longitudinal nature of the study allowed for the tracking of the students' understandings of several key concepts of geometrical optics over the first two years. The students' understandings of geometrical optics then formed the basis of exploration of their mental models of the nature of light in addition to their views of the nature and function of scientific models over the students' 12th year of schooling. It must be noted that the findings as they relate to the students' views of the nature and function of scientific models is not reported in this paper. During the Year 12 teaching stage the students studied physical optics and quantum ideas and engaged in discussions about the role of models in science. The pertinent research question relating to this part of the study was, 'What mental models do students have about the nature of light and how do they change in response to a teaching sequence about the scientific models of light?"

Methods

The research design relating specifically to the exploration of the students' mental models of light centered on three semi-structured interviews and three questionnaires administered over a period of several months in the students' 12th year of schooling. The teacher/researcher also made classroom observations. The first two interviews occurred before the teaching stage and the third interview was held after the teaching stage. The questionnaires were administered before and during the teaching stage.

The first of the interviews explored the mental models of the nature of light constructed by the students in explaining situations as they related to the key concepts addressed in the first two years of the study. The data from this interview revealed three different models used by the students to explain various phenomena of light. These models then formed the basis of a questionnaire that was administered to the students some three months after the first interview. It contained questions that centered on students selecting an appropriate model, with reasons, for different phenomena of light. The interview and questionnaire data for each student was fed back to them in the second interview. Students were asked about their own models and their thoughts about opposing models. The final interview occurred one month after the teaching stage and probed the students' mental models of light in the context of several phenomena of light. The first part of the Year 12 teaching stage involved eliciting and discussing the students' mental models of the nature of light on the basis of their responses to the questionnaires. For the rest of the Year 12 teaching stage the different scientific models, including the student-generated mental models, were evaluated in terms of their scope, and predictive and explanatory power in explaining various phenomena of light already met in Year 10 and Year 11 as well as new phenomena. The new phenomena included diffraction and interference effects of light, and the photoelectric effect. Difficulties encountered with any of the scientific or student's mental models in the explanation of specific phenomena of light were discussed and possible changes to models were explored. The opportunity was given for students to alter and revise their existing mental models as well as invent new ones.

Results

During Year 10 and 11 the students had expressed a high level of confidence in having a scientific understanding of several key concepts of geometrical optics that they showed on many occasions (Hubber, 2005). However, they had developed a mental model of light that related to their understanding of rays, which was inconsistent with scientific understanding. They believed that rays are actual constituents of light, conceptualized as continuous streams of material that can vary in size depending on the strength of the ray; the brightness of the light is then related to the strength of the ray or its concentration of number.

When asked about the nature of light at the beginning of Year 12 all students had maintained rays as part of their mental models of light but three of the students now believed that rays were representations of light rather than actual constituents (refer to Table 1). There was evidence of three distinct models described as the standard ray model, beam ray model and particle ray model. The standard ray model matches the scientific view of a geometric construction, in the form of an arrow, to show the direction of light propagation represented as water waves, the beam ray model represented light as continuous streams of material, while the particle ray model represented light as particles. When these models were presented to the students to explain various phenomena of light there was variation in their preferred models (refer to Table 2).

During the Year 12 teaching stage the students compared and tested their own personal models of light against the scientific models for different light phenomena. This resulted in each student achieving a scientific understanding of the nature of light in terms of the application of the particle scientific model or the wave scientific model to explain various light phenomena. Table 3 shows their preferred models to explain various light phenomena. The students were confident in using either particle or wave ideas depending on the phenomenon to be explained and were aware that their mental models of the nature of light had changed over the teaching period. The students' mental models had changed from conceptualizations of a ray to that of a photon. Just as there was variation in the mental models of a ray there were also quite subtle differences in their mental models of a photon (refer to Table 1). Four of the students had constructed hybrid models whereby photons acted separately to account for particle like behavior of light but acted collectively in waves to account for wave-like behavior.

Conclusions and Implications

This study found that students construct their own mental models of the nature of light, some of which are different to the scientifically acceptable scientific models, before and during the teaching of the scientific models. Prior to Year 12 the students held a mental model where rays were actual constituents of light but at the same time were able to successfully account for a whole range of geometrical optical behavior. By the end of the Year 12 teaching sequence the students could successfully account for different optical phenomena in terms of a particle or wave model of light. That is, they chose either a particle idea or a wave idea to explain a specific light phenomenon (refer to Table 3). However, in thinking about the nature of light, the students had constructed a hybrid model of light that related to the photon. This model had the photon with both wave and particle characteristics. One could argue that the students achieved a scientific understanding of light behavior despite holding a mental model of light which varied from the scientific models. On the other hand, one may view the students' understanding of light as limited as it does not contain a scientific view of the nature of light.

The construction of hybrid models raises an issue related to the students' understanding of the nature and function of scientific models. Alan had a view that light is actually composed of photons which he replaced from a model that he and the other students had, that light consists of rays. Alan's thinking is consistent with a 'naive realist' epistemology (Nadeau & Desautels, 1984), where models are direct copies of reality. On the other hand the other students changed to a more sophisticated epistemology where their hybrid photon models are considered representations of reality. However, three of the students, Christine, Evan and Frank, melded two quite distinct ideas into the one model, and extracting a particle idea when thinking about individual particle-like photons and a wave idea when particle-like photons act in great numbers. Such a thinking reflect a view that models are representations of reality, rather than a more scientific view that models are representations of ideas, or concepts, one has about reality. Beth's hybrid model maybe considered closest to the scientific view of the nature of models as her 'wavicle' view of a photon (refer to Table 1) was considered as a convenient image to think about light either as a particle or a wave.

*Student	Mental Models of	the Nature of Light				
	During Year 10 &	During Year 12				
		Before Year 12 Teaching Stage	Following Year 12 teaching Stage			
Alan	Light is composed of rays	Light is composed of rays that are continuous streams of material	Light is composed of photons that are particle-like in nature but act as a wave or ray in great numbers.			
Beth	Light is composed of rays	Light is composed of rays that are streams of particles	Light acts like waves or particles. Photons are theoretical entities that can be imagined as a 'wavelet' which metamorphose into particles or waves depending on which of a particle or wave idea is required to explain a specific phenomenon.			
Christine	Light is composed of rays	Light acts like waves or particles	Light acts like waves or particles. Light is composed of theoretical particle entities called photons with electrical characteristics that act like a wave in great numbers.			
Danielle	Light is composed of rays	Light acts like waves or particles	Light acts like waves or particles. The particles are theoretical entities called Photons. Waves are like water waves.			
Evan	Light is composed of rays	Light is composed of rays, called ray beams, which are continuous streams of material	Light acts like waves or particles. Light is composed of theoretical entities, called photons, which have both particle and wave characteristics.			
Frank	Light is composed of rays	Light travels like waves in a direction shown in diagrams by arrows called rays	Light acts like waves or particles. Light is composed of theoretical particle-like photons, which have electrical characteristics and behave as a wave in great numbers.			

Note: * Pseudonyms have been used for students in this study.

Table 1 Students' mental models of the nature of light

	Studen	t				
Phenomenon	Alan	Beth	Christine	Danielle	Evan	Frank
Light spreads out in all directions from the light source.	Beam	Particle	Beam	Beam	Beam	Wave
Each point on a luminous object emits light in all directions.	Beam	Particle	Beam	Beam	Beam	Wave
Light bends and slows down in going from air into glass.	Beam	Particle	Wave	Beam/ Wave	Beam	Wave
White light is composed of different colors.	Beam	Particle	Wave	Wave	Beam	Wave

Table 2 Students' preferred model(s) for various light phenomena before the Year 12 teaching stage

	Student					
Phenomenon	Alan	Beth	Christine	Danielle	Evan	Frank
Light spreading out from a luminous object	Particle	Wave	Wave	Wave	Particle	Wave
Isotropic emission of light from each point on a luminous object	Particle	Wave	Wave	Wave	Particle	Wave
Specular reflection	Particle	Wave	Wave	Wave	Particle	Particle
Diffuse reflection	Particle	Wave	Wave	Wave/ Particle	Particle	Particle
Color	Particle	Wave	Wave	Wave	Particle	Wave
Rectilinear propagation	Particle	Wave	Particle	Wave	Particle	Particle
Refraction	Wave	Wave	Wave	Wave	Particle	Wave
Photoelectric effect	Particle	Particle	Particle	Particle	Particle	Particle
Diffraction	Wave	Wave	Wave	Wave	Wave	Wave

Table 3 Students' preferred model(s) for various light phenomena following the Year 12 teaching stage

In teaching of the scientific models of light, care needs to be taken to make clear distinctions between the models, highlighting the view that they represent different ideas. Therefore, the teaching of the scientific models should occur at the same time the teaching of the nature and function of scientific models occurs. In respect of the teaching of light, the teaching about the nature and function of scientific models should occur at the same time geometrical optics is taught as the ray scientific model is used extensively. In addition, there is a need to explicitly focus on students' mental models as part of the pedagogical strategies adopted in optics as a mental model of light that was formed prior to or on entering school may be guiding students' thinking about the nature of light.

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Optics for the Blind

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Abstract

Italian and international historical and art museums have been setting up for several years tactile exhibits dedicated to blind or sight-impaired people, while in scientific museums a lot of work is still to be done. In this framework we propose an educational activity allowing the blind and the sight-impaired to put their "hands on light". We regard it as a starting point for alternative teaching method useful both for schools and museums. This experience not intended to be dedicated to a restricted target, indeed true integration rises not from the creation of activities strictly targeted to impaired capacity people, but from allowing everyone to share the same experience. Hands will be our eyes in the dark. The laboratory will be a journey of exploration of the mysterious nature of light. We will move from the concept of light in the ancient times up to the quantum theory and to atomic and molecular models of today's physics. The sensation of warmth caused by an intense light beam on our hands leads us to the straight propagation of light, and to the laws of reflection. With other experiments we study the formation of images in the eye and the perception of distance. Several mechanical models and the analogy with sound waves illustrate various theories of light and of matter. There are also hands-on experiments on electricity and magnetism. For instance, a particular kind of glove allows us to "touch" the magnetic field.

A didactic activity on the physics of light addressed to the blind and visually impaired is not to be regarded as provoking. It would be more appropriate to consider it an important responsibility, both for schools and museums.

Scientific subjects have always been considered an essential part of the education and nowadays it is more and more so. Mathematics, physics and chemistry play a fundamental role in the school curricula and help the students to acquire important skills. However, the blind and visually impaired have been often excluded from these activities because of lack (real or pretended) of appropriate didactical aids and because of instrumental difficulties. Aim of this educational activity is thus to propose to the teacher proper methods and several tactile experiences in

order to enable him to teach physics (optics in this case) in an unusual and effective way, albeit one of their students has a visually impairment. On the other hand, museums play a fundamental role in the maintenance and diffusion of cultural heritage. They are also supposed to have a leading and exemplar role in spreading a culture of attention, of accessibility for everyone – tough sometimes they are a discouraging example of exclusion. The methods, objects and experiences here proposed are part of a project for developing museum activities and exhibitions accessible to everybody.

Hands and Beyond

The fact that the major part of information reaches us through sight has caused the preconception of a biological supremacy of the eye compared to other senses, which were considered of secondary importance. For a long time, the organization of human societies suffered this kind of approach.

But the blind and visually impaired are able to achieve many abilities, as the sighted. They may learn how to use all the cultural instruments of the society they belong to. In order to do this, they need to follow different ways, to apply different solutions. These necessities descend from the fact that there are qualitative differences in the way blind people see the world - they can't be considered just as sighted persons with bandaged eyes - it is necessary to comply with these differences and to take advantage from them.

Impairments, with all the obstacles to go through, force the subject who undergoes their effects to develop new strategies to overtake difficulties. As already stated by Vygotskij [1], blindness is not just the lack of the sense of sight, moreover it enables the re-arrangement of all human skills. It gives rise to new abilities by changing the usual organization of personal resources. Therefore, blindness is not only a defect, a weakness, but may give also an unexpected strength.

Despite the illuminist theory of the senses' vicarship – responsible of the preconception that all blind people, and visually impaired, would have sensational touch and hearing – the "new abilities" do not involve the senses, but "psychical functions" as attention, memory and concentration, allowing an original arrangement of the data provided by the active senses.

Tactile exploration

The visual perception – instant and synthetic – tend to cause a rapid dispersion of attention due to concurrent competitive stimulus. The tactile exploration, instead, leads up to a knowledge distributed in time, therefore more analytical and able to hit particular details and aspects. While visual perception is comprehensive and proceeds outright into more detailed depth by focusing on the different parts of the structure, the *haptic* (tactual kinesthetic) perception stems from the analysis of the single parts of the object to obtain the entire structure of it through a synthesis of all the information gained.

That means that through the eyes we perceive the shape of the what we see without the need of a conscious reorganization of the information perceived, while the haptic perception of things must be followed by a processing of the simple elements perceived in order to recognize the object. When a visually impaired explores an object his hand holds and releases it again and again. While doing this, the subject gets several data concerning the physical characteristics of the object, as hardness and resistance, leaving temporarily out the problem of the shape of it. Indeed, a preliminary investigation of an object is fundamental in the field of haptic, although not so necessary for the visual perception.



Fig. 1 – Tactile exploration of vibrating string

Kept on hand

Not the whole hand is involved is the exploration, but only part of it: the thumb and the forefinger. These two fingers are particularly sensitized to the perception and analysis of shapes. During their haptic investigation, the blind and the visually impaired usually follow a step-by-step procedure: they move their fingers, gently and progressively, along the surface of the object.

Closely related to the step-by-step perception, is the cinematic principle, which states that a step-by-step perception can be achieved not only by the movement of the hand on the object, but also by the movement of the object while the hand is still. What becomes fundamental is the relative movement, because the idea of shape is the result of subsequent different tactile perceptions.

It is important to keep in mind these issues while developing a tactile object or a hands-on exhibit. These objects may be either entirely novel or they may be well-known hands-on experiences adapted to fit the deeper skills described.

Objects, Models and Experiences in Optics for the Blind

The educational activities proposed allow the blind and the sight-impaired to put their "hands on light". The laboratory deals with several theories on the nature of light. We start from the concept of light in the ancient times up to the quantum theory and to atomic and molecular models of today's physics [2].

Ray Optics

The sensation of warmth caused by an intense light beam on our hands leads us to the straight propagation of light and to the reflection laws. This kind of perception of light as radiated heat is familiar to the blind from the exposition to sunlight.



Fig 2 (a) light and heat radiation setup (b) hand – the sensor

Paying attention to the necessary safety precautions, it is possible to obtain a cylinder of radiated light. Only a simple lamp and a few screens with apertures are needed (Fig. 2a). The hand is the sensor, and it is possible to move it inside and outside the light cylinder (Fig. 2b). The cylinder may also be interrupted moving the screens. Thus we inquire and learn about concepts related to rectilinear light propagation and shadows formation and shapes. Mirrors are then used to reflect light and direct it in the shade, where it will be detected by the hand. Together with these concepts, the theory of ray optics is introduced.

The theory, which regards light as a bundle of rays, is approached by means of wooden or metallic thin long sticks, concrete models of light rays. As every other object of the activity, the rays are painted for the sake of the sighted part of the audience, since the activity is planned for both the blind and the sighted. The whole set of phenomena that the theory encompasses may be probed playing with these model rays: propagation from a point source and shadows (Fig. 3a), reflection and image formation (Fig. 3b) are chief examples.



Fig.3 rays of light modeled by means of thin sticks

The corpuscular theory of light – which regards rays of light as made of tiny corpuscles – is portrayed with the help of popular games. The light-corpuscles are modeled by darts or little balls, shot at a target, or reflected from a wall. These games offer a platform for a narration elucidating the various concepts.

Wave Optics

The wave theory of light is first approached by hand-grazing several vibratory motions. First, we make waves on the surface of water and detect them with a floating ball (Fig. 4a). In some sense, it is a development of the common ripple tank with shadows images of the waves. The improvement consists in the use of floating foam balls as sources and detectors of waves. This setup allows detecting even the diffraction from an obstacle or a slit.



Fig 4 (a) Touchable ripple tank. (b) Clay model of a plane wave

Various rippled surfaces are replicated by models made of clay (Fig. 4b) and other materials. Clay is one of the friendliest materials for tactile explorations. These clay surfaces are attractive objects, embedding mathematical elegance, and with a ringing familiar tune as well. They are of much help in describing clearly the concepts of wavelength, frequency, amplitude, wavefronts, interference... To account for the phenomenon of interference we use waves of cardboard (Fig. 5a) where the sum of amplitudes becomes tactile.



Fig. 5 Waves of Cardboard. (a) touching (b) interference

The "wave of cardboard" may also be regarded as a development of the "ray–stick". Several *cardwaves* of different colors are used, each characterized by its wavelength. The cardwaves are used to show how wave optics is consistent with ray optics, and also how the former expands beyond the latter, being able to give account of a wider range of phenomena.

The visually-impaired has learned to use his hands to gather a lot of information. Sometimes every finger takes part in the exploration. This skill is at play in the observation of the spacetime evolution of physical quantities. The chief example is wave motion and the formation of stationary waves due to interference (Fig. 6). The visually-impaired is able to localize with utmost precision the nodes and the peaks of a vibrating string (Fig. 1) or slinky.



Fig. 6 stationary wave in string and how it is being probed by hand

Electromagnetic Optics

There are also hands-on experiments on electricity and magnetism supporting the electromagnetic theory of light. For instance, a particular kind of glove – we named it *manosensore magnetico*! (Fig 7a) – allows us to "touch" the magnetic field.

This glove has many little pieces of iron attached to every finger that are thus variably attracted in the proximity of powerful magnets, allowing different kinds of exploration of the magnetic field: sometimes the field around the magnet may be "scanned" in different directions with one finger that is kept at constant distance by the other hand (Fig. 7b), while sometimes it may be sensed with the whole hand in different points contemporaneously.



Fig 7. (a) manosensore magnetico (b) examining the magnetic field by touch

Quantum Physics

The wave-corpuscle dualism is approached together with the foundations of quantum theory and the radiation-matter interaction. Orbital-models of atoms and solids, spacefilling models of molecules are helpful in this regard. Different atoms have different coatings, thus allowing their recognition by tactile exploration (Fig. 8).



Fig 8. models of atoms and molecules

The described activities do not rely on applets, drawings and other visual experiences. Instead, both the observation of phenomena and the tools of the theory needed to account for them rely on concrete models to be explored by touch.

Concrete models are indispensable indeed in the physics teaching (both experiment and theory) for the blind and the visually impaired. This is another facet of the importance of models in the teaching of physics.

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The Coefficient Of Restitution Model: How Realistic Is It?

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Abstract

The concept of a 'coefficient of restitution' is often introduced in the context of a model describing inelastic collisions. In this paper we attempt a critical assessment of the model. Some computer-based experiments will be described which help explain the concepts underlying the model.

Introduction

In another paper at this conference (O'Sullivan 2006) one of us has argued that physics teaching could benefit if teachers were to articulate more explicitly the nature of the particular model underlying each topic being taught. In particular, it is contended that clear distinctions should be made between models involving fundamental laws of nature (e.g. Newton's laws), those entailing equations of state (e.g. Ohm's law, Boyle's law) and more primitive models designed to describe, often quite crudely, observed macroscopic phenomena (e.g. 'laws of friction'). The experiment described in this paper was designed and developed to assist students to understand the limits to a commonly used model in the lastmentioned category, namely the use of the concept of a *coefficient of restitution* to describe collisions between two bodies.

The coefficient of restitution is usually defined (Synge 1970) as the ratio of the magnitude of the relative velocity of the bodies after collision to that beforehand, that is

$$e = \frac{|\mathbf{v}_2 - \mathbf{v}_1|}{|\mathbf{u}_2 - \mathbf{u}_1|} \, .$$

It can be shown easily (Mansfield 1998) that, in the c.m. frame, the

$$\frac{\Delta E}{E_0} = 1 - e^2$$

fractional energy lost in the collision is given by

where E_0 is the total kinetic energy of the two bodies before the collision¹. Thus e = 1 represents the case of an elastic collision and e = 0 that of a totally inelastic collision.

The issue surrounding the underlying model, in this case, centers on the extent to which the quantity e, and hence $1 - e^2$, is a constant. That is to

say, to what extent can *e* be treated as a characteristic of all collisions between the two bodies or is it simply a number that characterizes the energy lost in a particular event? In the latter case there is effectively no model involved whereas, if *e* can be treated as a characteristic of the interaction, the model (a *'law of collisions '*?) asserts that the loss of energy is proportional to the initial energy, that is

 $\Delta E \propto E_0.$

Since there does not appear to be a fundamental *a priori* reason why such a 'law' should apply in real collisions between macroscopic bodies, it was felt that an experiment to investigate the extent of applicability of such a 'law' and related issues would be instructive.

The experiment

The experiment chosen to study a collision process is shown in figure 1. The use of a compressible helical spring to provide an interaction between colliding bodies, which has a sufficiently long impact time to enable the details of a collision to be investigated, is familiar in many schools and universities. Collisions between carts, or between one cart and a fixed object, moving on a track in a low friction environment are particularly suitable for such studies. Because, in the case of our experiment, it was felt that it would be interesting for students to make measurements before, during and after the collision, standard techniques for measuring positions and speeds, such as ultrasound motion sensors or light gates were not sufficiently accurate. Since the cart used has built-in magnets, it was decided to use an appropriately calibrated magnetic field sensor² to measure the position of the cart. The force on the fixed end of the spring was measured by a force sensor³ rigidly fixed to the track and connected to the spring as in figure 1. Since the target is fixed to the track, all observations are in the c.m. frame.



Figure 1: View of the experiment

Both sensors were connected to the e-ProLab data acquisition system developed under the ComLab project4. Any standard data acquisition system may be used for the experiment described but, in contrast to other systems, e-Prolab provides open source information for development of specific applications and can easily accommodate homemade and most commercially available peripherals. The e-ProLab screen for a typical collision event is shown in figure 2. Appropriate data can be cut and pasted into a spreadsheet application and curve-fitting tools used to determine the speeds of the cart before (U) and after (V) the impact with the spring.



Figure 2: Typical plot of the position of the cart (blue) and reading of the force sensor (red) versus time. The force is negative because a compressional force on the sensor is measured as negative. The impact time of the overall collision is the time between the two vertical markers.

A number of important concepts in analytical mechanics may be investigated by students.

1. To show that the momentum transfer is equal to the integral of force over time

The e-ProLab software allows for the determination of the area under the force-time curve which enables the comparison of the momentum transfer, M(U + V) where M is the mass of the cart, with $\int Fdt$. Sample results are shown in table 1.

2. Measurement of the force constant of the spring

The force constant (k) of the spring may be determined from the data in figure 2 in two ways.

(i) The time of contact, ≈ 80 ms in the case of the data in figure 2, is clearly one half of the period of oscillation of the system comprising the spring with the cart attached. Since this period is equal to $2\pi\sqrt{(M/k)}$, the value of k is easily determined.

			$\int Fdt$ (N	
run	U (m/s)	V (m/s)	s)	M(U+V) (N s)
M 1N	0.085	0.084	0.044	0.042
M 2N	0.167	0.164	0.080	0.082
M 3N	0.268	0.256	0.140	0.130
M 3,5N	0.340	0.327	0.170	0.166
M 4N	0.396	0.330	0.190	0.181
M 5N	0.478	0.465	0.240	0.235
M 6N	0.494	0.494	0.240	0.246
M 7N	0.676	0.560	0.290	0.308
M 8N	0.803	0.783	0.400	0.395
M 10N	0.831	0.798	0.410	0.406

Table 1: Comparison of momentum transfer and [Fdt for ten sample collisions

(ii) The data in figure 2 can be presented in the form of an F-x plot (figure 3). The slope of the portion of the plot corresponding to the collision, determined for example by exporting the data to a spreadsheet utility, enables the calculation of k.



Figure 3: Typical force versus distance plot

Sample results are presented in table 2.

	$RUN \rightarrow$	W 1,7N	W 1,5N	W 1,3N	W ,90N	W ,60N	W ,50N	W ,35N	W ,17N
<i>k</i> from i time	mpact	58.5	58.5	58.5	58.5	58.5	58.5	61.4	58.5
<i>k</i> from curve	F-x	57.4	57.1	55.1	60.2	58.0	55.7	54.1	51.0

Table 2: Sample results from the measurement of the force constant of a spring

3. Energy conversion during impact

The maximum force (F_{max}) experienced by the spring and the corresponding maximum compression (X_{max}) may be measured from the data in figure 2 and similar plots for other collision events. The corresponding stored potential energies $(\frac{1}{2}kX_{\text{max}}^2 \text{ and } F_{\text{max}}^2/2k$, respectively) may be compared to the initial kinetic energy of the cart (table 3 below).

RUN -	$\rightarrow W_{1,9N}$	W 1,7N	W 1,5N	W 1,3N	W ,90N	W ,60N	W ,50N	W ,35N
kinetic energy before impact ¹ / ₂ MU ² (mJ)	= 14.16	14.03	11.49	8.48	6.22	2.98	2.54	1.34
energy of compressed spring ¹ / ₂ kX _{max²} (mJ)	=	12.19	10.04	6.73	6.28	2.88	2.32	1.16
energy of compressed spring $F_{\text{max}^2/2k}$ (mJ)	= 14.18	15.48	11.60	8.35	5.92	2.76	2.23	1.10

Table 3: Sample comparison of kinetic and potential energies in eight collisions

4. Energy lost in a collision

In all situations involving collisions between a cart and a compressible helical spring the energy loss is small, that is *e* is close to unity. It can be seen, however, that some energy is always lost; energy is always observed in the form of post-collision oscillations as seen clearly in figure 2. This observation provides students with a useful insight into the nature of non-elastic collisions in general. Some amount of energy is also lost as a result of friction between the cart and the track.



Figure 4: Experimental arrangement showing a mass attached to the spring

It is often more interesting for students if the study of energy loss in collisions is carried out when a mass (~ 10 g) is attached to the end of the spring (figure 4).

In this case there are three principal sources of energy loss, namely

- a) Energy lost during the initial impact of the cart with the attached mass. This collision may be assumed to be totally inelastic; that is, $\Delta E = E_0/(1+M/m)$. The issues here are interesting but complex; it is hoped to discuss this question elsewhere.
- b) Energy transferred to spring oscillations $(F_m^2/2k)$.
- c) Energy lost by 'friction' (\approx friction force $\times 2X_0 = 2(M + m)X_0a_f$, where a_f is the mean acceleration due to friction between cart and track) while the cart is in contact with the spring. A value of the acceleration may be estimated by fitting a quadratic function to the distance-time data recorded.



Figure 5: Typical plot of the position of the cart and the reading on the force sensor versus time when a mass is attached to the spring

In this case the energy transferred to oscillations of the mass-spring system $(F_m^2/2k)$, where F_m is the amplitude of the force oscillations observed) is much clearer (figure 5) and can be measured more easily. Table 4 shows some sample results from this analysis.

		run 4.1	run 4.2	run 4.3	run 4.4	run 4.5	run 4.6	run 4.7	run 4.8
Incident speed (U)	(m/s)	0.10	0.18	0.25	0.31	0.40	0.48	0.57	0.61
Collision energy $(E_0 = \frac{1}{2}MU^2)$	(mJ)	1.26	3.95	8.13	12.42	19.96	28.91	41.08	46.42
Energy lost in inelastic collision	(mJ)	0.09	0.29	0.60	0.91	1.47	2.13	3.02	3.41
Energy in oscillations	(mJ)	0.02	0.08	0.16	0.30	0.56	0.76	1.06	1.26
Energy lost to friction	(mJ)	0.01	0.02	0.03	0.03	0.05	0.05	0.07	0.06
Total energy loss (ΔE)	(mJ)	0.12	0.39	0.79	1.25	2.11	3.03	4.15	4.73
$\sqrt{\{(E_0 - \Delta E)/E_0\}}$		0.952	0.949	0.950	0.948	0.947	0.948	0.948	0.948
e = V/U		0.900	0.944	0.961	0.952	0.958	0.955	0.960	0.949

Table 4: Example of audit of energy loss in collision (mass attached to the end of the spring)

5. Study of the coefficient of restitution

Values of the coefficient of restitution, measured as the ratio V/U, are included in table 4 above. The corresponding energy loss ΔE calculated in the table can be used to determine $\sqrt{\{(E_0 - \Delta E)/E_0\}}$. The results obtained are compared in figure 5; the error bars indicate approximately one standard deviation.



Figure 5: Typical plot of the dependence of the coefficient of restitution on energy

Having discussed these and similar results using springs of different strengths, students may conclude that, within the accuracy of this experiment, the underlying model is applicable to most of the collision events studied but that there may be some systematic variation from the model at lower energies. They may conclude that the applicability of the model requires that the principle sources of energy loss must be proportional to E_0 , within the accuracy of the experiment. Sources a) and b), but not c), in section 4 above satisfy this requirement. Further considerations may lead to speculation on situations in which the model is unlikely to be applicable and to proposals for further experiments.

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$$\frac{\Delta E}{E} = \frac{m_2}{(1-e^2)}$$

¹ In the laboratory frame $\overline{E_0}^{-1} \overline{m_1 + m_2}^{(1-e^{-1})}$ where m_1 and m_2 are the masses of the moving and target particles, respectively. op. cit. page 138.

² <u>http://www.vernier.com/probes/mg-bta.html</u>

³<u>http://www.vernier.com/probes/dfs-bta.html</u> or

<u>http://store.pasco.com/pascostore/showdetl.cfm?&DID=9&Product_ID=1468&De</u> <u>tail=1</u>

⁴ For details of the ComLab project see <u>http://e-prolab.com/comlab/</u>

A teaching approach about acoustics integrating different ICT and combining knowledge from different fields

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Abstract

A teaching sequence about acoustics has been prepared for a schooluniversity partnership with secondary school students without prior instruction on the subject. It is implemented in a computerized laboratory at the university and different ICT tools (applet, simulation software and MBL) are integrated. Research studies of science education, pedagogy and psychology provided foundations for the sequence. The paper describes many of the different and relevant components that a sequence needs to integrate for taking benefit of the theoretical knowledge from the above fields. Analysing outcomes from a teaching sequence without taking care of the teaching approach used can disguise the real results or lead to misinterpretations.

Rationale

The elaboration of evidenced-based teaching sequences that has to be applicable in real situations turns out to be an integrative process that needs to take into account research results coming from different and separate fields. This means that knowledge from pedagogy, from psychology, from science education and, of course, from science itself, have to be combined. Moreover, if it is decided to integrate some informatics tools along the sequence, it is also necessary to incorporate knowledge from the ICT field: suitability of the tool, properties, etc. In the sequence presentation it is opportune to suggest some teaching approach for an efficient way of using the sequence in a specific context and for a particular school level (Andersson, 2003).

For us, teaching Physics in school is conceived as one of the school activities and so, as an element that should contribute to the general education of the student developing their cognitive capacities as well as the social ones, encouraging both their knowledge and their skills, promoting their positive attitude for science issues as well as for learning in general. We cannot disengage a Physics teaching sequence of the environment where it will be taught and so, the approach that the teacher will offer. The achievement of the objectives is not only influenced by the selection and sequencing of the contents but also on the teaching approach, the class atmosphere, the way to propose the students' activities, etc. Differently said, the learning outcomes are very much dependent on the teachers' conceptions about understanding and learning and, on the circumstances taken into account when planning and when implementing each piece of the sequence.

Under such perspectives, we present relevant steps of an innovative sequence about acoustics integrating activities proposed for students using three different informatics tools. Its selection and the suitability of each of them according to its peculiarities are also described. The sequence relies on research results about the teaching and learning of waves (from Maurines 2003, Witmann et al. 2003, Tarantino et al, 2005), and about general principles on learning and understanding Sciences (Donovan and Bradford 2005, Gunstone 1999 Schraw et al 2006), on sequencing science contents (Buty et al. 2004, Leach & Scott 2002, Meheut and Psillos 2004) and on reading images (Kress 2006) etc.

A teaching sequence integrating applet, freeware application and MBL technology

Our intention here is to present an evidence-based teaching sequence that is being changed according students response trough a process of developmental approach (Lijnse, 1995). The main goals of the sequence are to make pupils aware of sound pollution, increase pupils understanding of what is sound, how it is produced and how it can be attenuated and also to make teachers cognisant of ways to integrate different ICT in science classroom. Pieces of research around students understanding each of the concepts involved, about using the ICT and, about the sequence' utility for teachers' professional development are no matter of this paper.

An special scenario: REVIR

The scenario where the sequence is implemented is not usual. The REVIR is an initiative of the research centre CRECIM in which secondary school students of Catalonia have access to a computerized laboratory at the University (Faculty of Education). CRECIM prepares teaching sequences addressed to some scientific content integrating different ICTs. Students 12-16 years spend a complete morning working in small groups with specific material prepared for the session. The teachers of these students attend also the session in order to observe students' response working with computer tools and possible ways to implement them in their own lessons.

Relevant features of the sequence on acoustics for students 12-14 without prior instruction

1. Contextualizing and intrinsic motivation. Establishing a central core

From the literature we know that in order to allow intrinsic motivation to develop, three basic needs should be addressed: (1) the support of autonomy, (2) the support of competence and (3) the support of social relationships. (Krapp 2002 and Mikelskis-Seifert, 2005). This view was considered when planning the sequence.

As a way to engage students in the subject, the sequence begins posing a meaningful problem to the students:

We are a rock band practising in the attic of a building. The police have come while we were practising due to some complaints from the neighbours. We must reduce the sound intensity but we have no other room for our essays. How shall we manage?

Our purpose is to place students in a real context with some significance for them and to give directionality to the tasks that will be done during all the session.

To become engaged in solving a question, to feel challenged of finding a solution of a problem or satisfying a curiosity are reasons for an intrinsic motivation. We wish students experience a **need to know** (Lijnse & Klaassen, 2004) and such approach seems to be successful.

2. Communicating the session goals

For helping students to face this complex problem within the time limitations they have, some material has been prepared which guide the students across the different steps necessary to solve the problem.

Wha	t we need for solving the problem?
In o	rder to know how to reduce sound intensity it is
nece	ssary to recognise it. That drives us
1. U of vi	nderstanding what is sound, from the physics point ew
2. W sour	orking with special instruments for visualizing d.
3. A	nalysing sounds produced by students' voice.
4. A or a	nalysing sounds produced by musical instruments n amplifier
5. M	easuring sound intensity
and,	at the end:
5. F bv ti	ind ways for reducing the sound intensity produced ne rock team

However, before starting we try to assure that students understand the steps of the general sequence, become aware of what is expected from them and be clear about our final goals. So, students' **metacognition** is promoted in order they can anticipate their way to work.

Fig 1

3. Exploring students' preconceptions

Sound and noise belong to the students' everyday experience and so, it is expected some previous rudimentary mental representation about them. Students are asked some questions for their conceptions to emerge, which later, through engaging in a socratic dialogue, can be driven to the interest/need to know what sound really is.

4. Building the wave concept by means of an applet

An essential idea for understanding sound seems to be the concept of longitudinal travelling wave. A feasible way to introduce it to students is to use an applet, which overcomes the general difficulty of static representations of dynamic phenomena. As Monaghan & Clement point out "simulations are particularly useful to scaffold students in their **building of mental representations** of not "easily" visible models or phenomena (DNA, radioactivity, etc). The created mental images should play an important role in understanding and learning. There is growing evidence that forming a visualizable model as a representation that is more general than single examples, but not as abstract as mathematical, may be central for understanding in science students". (Monaghan & Clement 1999).



Which simulation or applet to chose? As Tarantino et al. (2005) remark when referring to wave propagation, students find very difficult performing the shift from the two levels of representation: one involving the analysis of the pulse as a whole and the other one describing the behaviours of the atoms/molecules of the medium. We selected an applet that seemed to be able to avoid such difficulty, showing the relation between both representations. The following

Fig 2 image gives an idea of the applet we have used. Graph is interpreted as the representation of the change of pressure evolution of air particles.

http://www.ngsir.netfirms.com/englishhtm/Lwave.htm¹⁸

5. Analysing waves using Audacity

Having understood the link between the sinusoidal representation of sound waves and the actual variations of pressure of air molecules (sound), students are at this point ready to analyse sound waves. With this purpose, we use the freeware application Audacity, which objective is to reinforce the construction of the wave model and, as well, to make students aware of wave's diversity.

Students analyse the waves of their sounds in front of a microphone by means of Audacity, which draw graphs Δ pressure-time. Students feel very engaged in using an ICT allowing them to see results of their own real actions (with the voice) reflected in the computer screen. The application makes possible that students realise that an specific sound, as the one of a vowel, has a very similar shape on the screen, whatever the emitter/student.

¹⁸ The meaning attributed by students to the representation in the applet was analysed to detect its efficacy but, it is not here the place where to describe its results.



The work with waves having similarities and differences makes easy to establish the need of new concepts such as Fig. 3 **period** or **frequency**. These two scientific terms evoke something coming from the waves of their own sounds and usually they actually become meaningful along the activity. The scaffolding process of this task for such knowledge construction is reinforced by students working with their peers in small groups along the whole session.

6. Extending concepts to different contexts

The generalization of the concepts of wave, period or frequency can be achieved by applying them to different musical instruments. Sounds from real instruments or from computer files corresponding to some frequency (i.e. 440 Hz) are also represented and analyzed with Audacity.

7. Linking each new step to the central core

The students' enthusiasm analyzing their voice cannot hide the main objective of the session: to solve the "rock team problem". Students are warned about the steps covered and the ones that are lacking. Along the path teacher retrieves and continuously establishes links among the pieces or fragments. We assume that: "Information stored in memory, if organized around core concepts, can be much more effectively retrieved and applied than isolated pieces of information. The reason that experts in a field remember more than novices is that the former see information as organized sets of ideas and novices see it as separate pieces" (Donovan & Bransford, 2005).

8. Realising the need of new instruments and recognizing the limits of Audacity

Until now, Audacity has supplied graphs representing the pressure-times of a single point where the wave is travelling but no any graph that would indicate the pressure that different points of the path receive in a particular moment (graph Δ pressure-position). Measuring the changes of sound pressure in different points, that is the level of sound, close or far from the sound source, should be done through new equipment.

9. Measuring levels of sound with MBL technology

Now students learn to measure levels of sound. They can establish certain relationship between the sound they perceive and the sound level that a sonometer measures (in decibels). Sounds, as computer files, opened through Windows Media Player, are reproduced by loudspeakers connected to the computer and registered by the sound sensor.

10. Integrating concepts

Scale intensity in dB and Pa is presented and some exercises proposed in order to integrate the previously built concept of change of pressure in particles of air (Pascals) and the new but more familiar one: sound level (dB). As Taber (2006) says: "Learning topics as isolated chunks of knowledge is less useful, more difficult and a lot less inspiring than a learning experience that reflects the conceptual integration that characterizes science".

11. An inquiry activity: Retrieving all the previous concepts needed to solve the preliminary problem through an open-ended labwork

At this moment, students are able to interpret the meaning of sound waves and to measure sound levels at different places. So, they are "equipped" to solve in a scientific based manner the "rock team problem". To solve the problem of attenuating the sound produced for their loudspeaker, students can use, at their own will, some boxes covered with different insulating materials. The instrument for measuring will be the sonometer of MBL equipment. This inquiry activity requires to think about the best experimental design to get clear conclusions.

12. Revising the sequence. Including a model of sound absorption

Having obtained evidence of the students' self-construction of mental representations about the reasons for the sounds absorption, we have included in the teaching sequence some rough ideas of reflection, refraction and diffraction of sound waves. The sequence was revised. Agreeing with the developmental research approach (Lijnse, 1995) the evaluation of the sequence drives to subsequent redesigns that are driven from theory-based expectations and from students' products and responses.

In brief

To summarize, we have presented a research based teaching sequence integrating different informatics tools, each of them appropriate for a specific purpose. The sequence has the perspective of a teaching approach that considers the social construction of knowledge, the relevance of understanding, categorizing and relating pieces of knowledge, the needs of an intrinsic motivation, the significance of making students aware of their progress, the teachers' importance of knowing the starting point of students. Our standpoint is the consideration that the elaboration of teaching sequences is an ongoing process of refinement that tries to join knowledge from very different fields, it intends to fit into students' needs and responses and develops through the analysis/research of its results.

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Making visible the invisible interference pattern

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Abstract

The two slits experiment is often used to explain the basic principle of interference of light. The position of the interference pattern depends on the phase difference of light from the slits. This experiment is used to explain our interference experiments with Michelson interferometer with the mirrors far from equidistant position. We propose an experiment where the distance between the interference fringes can be determined when the interference pattern disappears completely for a naked eye. We used a semiconductor laser with two fast photodiodes as sensors. The distance between invisible interference fringes was determined by observing the amplitude of the summed fluctuating signal as a function of distance between the sensors. The basic understanding of the phenomenon can be achieved using multimedia models such as sound equivalent of two slits experiment and animated drawings.

Introduction

The interference of light can be observed by naked eye only using coherent sources. In the following we will show how interference phenomena can be observed also with incoherent sources, using relatively modest equipment which is usually available in school laboratories. The experiments were already described [see (Verovnik & Likar, 1988), (Verovnik et al, 1992) and (Verovnik & Likar, 1999)]. Later on, we further developed the idea using Michelson interferometer since the relevant experimental parameters are better controlled (Verovnik & Likar, 2004).

In Michelson interferometer the full contrast of the interference pattern is achieved when the mirrors are in symmetrical positions with respect to the beam-splitter. The contrast vanish completely when the path difference of the arms is much bigger then the coherence length of the light.

It is generally believed the interference pattern is lost completely in this case. We will show how the information about the distance between invisible interference fringes can be measured.

Instead of using relatively complicated mathematical description, we have now developed some of the multimedia materials which enable the basic understanding of the experiment and its outcome. Among them is sound equivalent of the double slit experiment, where the relative phase of sound sources is changing with time. In some cases, to support the explanation of the experiments, the static drawings and illustrations do not give sufficient clarity. For this reason we developed several animated drawings which enable clear understanding of the phenomena. Using this material we expect that students are familiar with the basics of Young's double slit experiment and Michelson interferometer.

The sound equivalent of the double slit experiment

For the motivation and for better understanding further steps, the following experiment is advised. In the classroom two loudspeakers within the distance of about one meter will emit the sine-wave tones, one with the frequency of 800 Hz and the other one at 801 Hz. Asking students what we will hear, they usually give the right answer - beating with the frequency of one Hz. We can put additional question, concerning the energy: Each of the loudspeakers is emitting continuously the sound energy. This can be proved by putting the ear close to each of loudspeakers. Where does the energy go at the moments of silence? The answer is not trivial.

When explaining the importance of relative phase between the two sources the animation of interference field in front of the loudspeakers contributes substantially to the understanding of this phenomenon. Namely the whole pattern is turning in one direction so that at any selected point in the field the intensity is changing with one cycle per second (Fig. 1).

Fig. 1. Animation showing the turning of the interference field when the frequency of the loudspeakers at the bottom (not seen) differ for 1 Hz.



Double slit experiment and Michelson interferometer

In original Young's double slit experiment, for stable interference pattern constant phase difference of the light coming from each slit is important. Using two independent light sources instead two slits results in random changes of the phase difference and consequently in random changes of the position of the interference pattern. Slow detectors such as human eye can not follow fast movements of the pattern so the screen is seen as uniformly illuminated. Fast detectors such as photodiodes can detect the fluctuations of light at certain conditions.

We used Michelson interferometer since the control of interference pattern is relatively easy. De-coherence of two light beams can be achieved by increasing the length of one arm far beyond the coherence length of the laser light used. The phase difference of the light beams is then rapidly changing in a random way. This results in rapid random movement of the interference pattern on the screen. The interference pattern is blurred completely for the naked eye which detects only the average illumination of the screen.

Measuring fluctuations using two detectors

Instead using one detector, which measures random changes of intensity when the pattern is moving randomly, we used two detectors. Now the degree of correlation of the measured signals between the two detectors depends on the distance between them. The degree of correlation can give the information about the distance between invisible interference fringes. This can be a bit difficult to imagine and here again the animated drawings can help.

We present two animations with two extreme positions of the detectors. In Fig. 2a the distance between the sensors is equal to the distance between the neighboring interference fringes on the screen. In the animation the pattern moves uniformly to the right together with the sinusoidal shaped diagram but the position of the sensors is fixed. The height of the bars above the sensors follows the corresponding intensity at each moment. In this case time development of both signals is completely correlated. Both intensities reach the maximum at the same time and the same happens with the minimum and all intermediate values. By adding these two signals, the fluctuations are twice as big as with one single sensor. This is shown with the bar at the right side of the animation screen.

In Fig. 2b the distance between the sensors is increased to one and half distance between the interference fringes. The animation now shows no fluctuation in added signal. When the signal from one sensor increases, the other one decreases and vice versa.

The average magnitude of fluctuations is changing when the distance between the sensors changes, but the average added signal stays the same at all distances. By measuring the fluctuations of the added signal the distance between invisible interference fringes can be determined. It is simply equal to the change of distance between two neighboring positions where the fluctuations are at minimum or maximum. Fig. 2. The two animations where interference patterns together with the diagrams below are moving uniformly to the right. The sensors A and B are fixed. a - The distance between the sensors are equal to the distance between the two neighboring fringes. The added intensities fluctuate. b - The distance is equal to one and half of the distance between the fringes. The added intensities do not fluctuate.



The next interactive animation (Fig. 3) represents one more step closer towards the real measurement. Now the interference pattern moves randomly and the distance between the sensors can be controlled by pressing a key on the computer keyboard. The alternating component of the added signal is plotting simultaneously at the bottom of the screen.

Fig. 3. Interactive animation with random movable interference pattern. The distance between the sensors can be controlled by pressing a key on the computer keyboard. The alternating component of the added signal is plotting simultaneously at the bottom of the screen.



The experiment

The experiment itself is already described (Verovnik & Likar, 2004) and is therefore not theoretically and technically discussed here. The most important is the outcome which is presented in Fig. 4.
Fig. 4. Fluctuations of the measured signal changes periodically with increasing distance between the two light sensors - photodiodes. The period (about 6 mm) is equal to the distance between the fluctuating (invisible) interference fringes.



Conclusion

We believe the experiment and didactic multimedia material described here is of considerable didactic value. It demonstrates new possibilities for explaining the interference experiments with incoherent light sources which are usually not part of the curriculum. Indirectly these kinds of experiments demonstrate that the photons from different sources always interfere. Similar experiment we performed with the light from two independent lasers. The basic understanding of the experiment and its outcome can be achieved by the use of presented didactic multimedia models in relatively short time.

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Primary School Physics

Prospective primary teachers' functional models of electric and logic circuits: results and implications for the research in teacher education

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Abstract

Results of a research on naïve mental models of prospective primary/elementary teachers about electrical and logical circuits are reported. All the models known from literature emerge from the study along with few new ones, although it seems that they are used in a nonconsistent way. Global view of electric circuits is adopted by a small fraction of the sample; moreover, it emerges that they feel rather uncomfortable in expressing their reasoning. Such results suggest, when addressing this content in training courses, to develop more consistent and scientifically acceptable models starting from prospective teachers' own models.

Introduction

Amongst the concepts addressed by Physics Education Research (PER), electric circuits probably rank after only force and motion in terms of the body knowledge nowadays available (Duit, 2004). Such an emphasis is justified by the fact that electric circuits are crucial in basic physics curricula and have applications in every-day life. This interest took shape as descriptive researches focused on students' *mental models*¹⁹ about the functioning of electric circuits (Fredette & Lochhead, 1980; Osborne, 1981; Cohen, Eylon & Ganiel, 1983; Shipstone, 1984). Efforts were put also in producing teaching sequences (McDermott & Shaffer, 1992b). Nowadays, due to a growing interest in understanding younger students' thinking in science (Euler, 2004), it seems that electric circuits are a fertile area for investigating young students' reasoning sequences (Glauert, 2005).

In this framework, research has also investigated elementary teachers' ideas on science (Harlen, 1997; Papageorgiou & Sakka, 2000; Trend, 2001; Rice, 2005) and physics topics (Kruger, 1990; Kruger, Palacio & Summers, 1992; Greenwood, 1996; Atwood, Christopher, & Trundle, 2001), showing that they often share the same alternative conceptions of their students. Studies on teachers' models about electric current have been carried out (StockImayer & Treagust, 1996; Borges & Gilbert, 1999) but, specially as far as Prospective Elementary Teachers (PETs) are concerned, this area has not been fully addressed.

¹⁹ In this paper, we share the view in which *mental models* are "personal, private, representations of a target" (Gilbert & Boulter, 1998; Greca & Moreira, 2000)

Drawing from all the above considerations, we set our study in the framework of mental models, exploited since nineties to make sense of students' alternative conceptions in science (Vosniadou & Brewer, 1992; Taber, 2003) and our *first* research question is:

RQ1a: "what are the main mental models which PETs use to make sense of the functioning of electrical circuits?"

RQ1b: "which is the level of consistency in the use of these models?"

Due to relevance of subject matter knowledge in teacher education research framework (Gess-Newsome, 1999), a *second* research questions will also be addressed:

RQ2: "how are the mental models used by PETs related to their content knowledge about electrical circuits?".

Methodology

Content analysis methodology has been used to tackle our research questions. Both manifest and latent content have been analyzed. Consequently, as research tool, an open questionnaire, QELC (Questionnaire on Electrical and Logical Circuits), has been developed. Questions are presented as problematic *situations*. We resorted to research-based tools to select eight situations: four from DIRECT 1.0 (Engelhardt & Beichner, 2004), two with high frequency of correct answers (about 80%), two with low frequency (less than 50%); two situations from the research described in Shipstone et al. (1988), both with more than 50% of not correct answers. One situation is adapted from McDermott & Shaffer (1992b). One situation addresses logical circuits (Testa, Michelini & Sassi, 2006). In situations 4 and 5 we focus on PETs' awareness of their understanding about electric circuits under both *selforiented* and *professional* viewpoints. The questionnaire is reported in Appendix.

From research results in literature about electric circuits it emerges a scattered use of models on behalf of students, i.e. different models emerge in response to different probes. This implies that searching for consistency in the use of one model across the situations provides few benefits. In addition, models used often say little about the global nature of the studied systems and have a weak predictive power. Therefore, to tackle RQ1a/b, we focus on two wider perspectives referring to qualitative type of reasoning about electric circuits' behavior (McDermott & Shaffer, 1992a; Duit & von Rhoneck, 1998): on one end, there are models which show a tendency to reason more locally and sequentially, on the other end, models featuring a more holistically oriented reasoning. We analyze the consistency of the use of these two perspectives.

To answer RQ2 we investigate, for some specific situations, the quantitative reasonings and their relations with the qualitative models used to describe and interpret the situation.

The sample consisted of 108 PETs, age 21-23, attending a science education laboratory course, compulsory for their four years university curriculum, held after the first part of the Physics Education course (Michelini, 2004). The course is carried out within the informal context of GEI exhibit (Bosio et al., 1997), and has exploratory nature (Bosio et al., 1998); electricity contents were not yet addressed when QELC was submitted. Reliability of the instrument has been addressed by a coderecoding procedure and later by means of two researchers' inter-rater agreement.

Main Results

RQ1a. From the analysis of the answers, PETs use the models of Table I^{20} , well known in literature (Borges & Gilbert, 1999; Métioui et al., 1996). Moreover, we found evidences for introducing six new models of PETs' qualitative reasoning (Table II). Categories of answers not classifiable are reported in Table III. The frequencies of all categories are reported in Table IV. The most popular models are "closed circuit" (chosen on average by 21% of PETs), "sharing" and "Ohm" (10% each). All these models emerge in at least seven out of eight situations, especially when circuits are constituted by a battery and more than one bulb. It may be plausible that PETs resort to articulated reasoning to explain complex circuits. Nevertheless, the rather low frequency of "Ohm" shows that our sample has an overall weak knowledge about electric circuits!

Although new models are not so frequent amongst the situations ("block" and "opposite" emerge only from one situation each), two of them, "subdivisions" and "elements", have rather high frequency for at least two situations; in particular, the model "subdivisions" has the highest frequency (32% and 37%) in situations where the circuits have three bulbs: it seems that PETs found it convenient for the description of circuits to "cut them off in pieces". Although this "reductionist" reasoning path may be useful to understand topology of circuits (see below), it can be potentially dangerous since local changes may be not recognized as influencing the whole circuit's functioning. "Functional" model emerges, as expected, for the situation involving electrical circuits simulating logical gates. In situation 4, about 75% of PETs use a different model when addressing to a fellow or a child; in situation 5, the percentage is about 70%.

RQ1b. More than half of PETs (on average $53\% \pm 19\%$) shows difficulties in expressing explanations about the functioning of electric circuits (Table V); when explanations are present, majority of PETs (on

²⁰ As for all categorizations, boundaries are not rigid and superposition/coexistence in the PETs occur. We have labeled each answer only with the predominant model, resulting in a uncertainty of about 4%. Further detailed analysis will not be addressed here.

average 75% \pm 22%) use models characterized by a more global perspective. As far as the consistency issue, we rated as consistent those PETs who adopted the same perspective for more than 70% of the cases in which they were requested to describe a circuit or to support a quantitative reasoning; the analysis of perspectives used by each PET confirms a scattered use of mental models with respect to the presented situations (Table VI). Only 17 out of 108 PETs showed a rather good consistency, the majority (15) using a global perspective; half of the PETs (54) uses more or less equivalently global and local perspective (Mixed); 37 PETs, for the majority of cases, do not answer at all. In situations 4 and 5, it emerges that almost all PETs, when answering, used models with the same (global) perspective when addressing to a fellow or a child.

RQ2. Correct answers' frequency to quantitative questions for situations 1-7 is reported in Table VII. In situation 1 about one third has recognized that three ammeters measure the same current, but only 12.5 % indicated the correct value of the ammeters (0.4 A); from table IV, we can argue that such correct answer has been plausibly triggered by an incorrect view ("elements" model) in which the ammeters are independent and therefore share the same current. As far as situation 2 is concerned, we found about the same percentage of correct answers as in literature, but this question was particularly difficult for PETs since more than one half did not answer. Only one fourth of PETs has recognized which were the circuits in parallel in situation 3, plausibly due to a view ("topological" model) focused more on spatial connections than electrical ones. Almost all of the PETs (92.3%) recognized the correct schema for the given realistic circuit in situation 4, focusing on small parts of the circuit ("subdivisions" model); in this case, such a view has revealed useful. In situation 5, about 38.3% of the sample (about the same frequency in literature) has identified the correct realistic circuit, plausibly due to views ("topology" and "closed circuit" models) that have lead PETs to focus their attention on the fact that "there is only one wire that connects the bulbs". Only one fifth of the sample did recognize that in both circuits A and C (situation 6) the bulb will light; about half of PETs indicates only circuit A, while 17% only circuit C: this result may be plausibly due to not having recognized the two terminals in the bulb or to a view focused on two opposite currents ("bipolar"). Finally, the frequency of not given answers (55.5%) shows a difficulty encountered by PETs with situation 7: the 70% of correct answers has not justifications ("*it is a parallel circuit*") or is based on incorrect reasoning ("constant current" and "sharing" models).

Discussion and implications

The results confirm that the sample shows the same difficulties known in the literature, but other problematic issues not yet addressed have arisen as well, as the tendency to 1) subdivide complex circuits in smaller ones without taking into account their relationships and what is their role within the circuit's global topology, and 2) justify circuits' functioning in terms of quantities (charge/current/energy) shared amongst the circuits' elements without taking into account their electrical connections, but also the inability to 3) transform correct qualitative reasoning into coherent quantitative answers, and 4) recognize the role of measurement apparatuses. Since individuals in our sample will not attend any additional physics course during their university career and will probably teach in primary and elementary schools within two years, such results are interesting since they spread light on elementary teachers' content knowledge about an area of physics which is important at both elementary and secondary level.

By shifting the attention from simply listing mental models to framing them into the wider "global/local" perspective, this study mainly allowed us to conclude that, although global perspective is familiar to prospective primary school teachers, this hardly results in correctly dealing with circuits' behavior. Two consequences follow from this result: - conceptual knots about current are not due only to the consumption/attenuation/sequential models but also to views focused on polarities (plus/minus) of batteries independently of the circuits' global topology; - "Ohm" model does not imply the overcoming of the difficulties in quantitatively determining the current in complex circuits' wires. Moreover, more than one third of our sample did not feel comfortable in expressing their reasoning, specially when addressing to children: it is confirmed that the lack of self-confidence in the scientific knowledge plays an important role (Rice, 2005).

As far as the primary teacher education research framework, as also recently stressed in a wider outlook by literature (Justi & Gilbert, 2003; Crawford & Cullin, 2004), our study calls for a major emphasis on investigating teachers' alternative models or *views* about the content to be taught, in this case, electric circuits.

The need to increase prospective primary and elementary teachers' awareness of mastering models with more interpretative and predictive power also emerges. However, in this content area, dealing too early with the particle model may lead to potentially dangerous misconceptions that can impair the understanding of related physics concepts (Borges & Gilbert, 1999). To address this issue, our study suggests to focus on electric circuits' elements and sub-structures since they are key entities on which teachers and students' reasoning is built upon: the role of and the ways in which such entities interact should be explicitly addressed and clarified. The "functional" model, emerged in situation 8, may be especially useful to develop a more consistent global perspective since it allows to easily identify the influence of elements, considered as interacting yet independent entities, on the circuit's global functioning.

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Code	Model Name	Description	Perspective
А	Unipolar/Sink	Flow of current from one terminal of the battery to the bulb	Local
В	Split	Upon entering/leaving two circuit's components current/charge splits always into two equal parts	Local
С	Consumption/Attenuation/Sequential	Current is consumed as it goes trough the circuits	Local
D	Constant current source	Modifying circuit's elements does not affect current supplied by the battery	Local
Е	Bipolar/Clashing currents	Plus/minus (+/-) currents/charges flow toward the bulb from each battery terminal	Global
F	Sharing	Battery shares its current/charge amongst the components of the circuits	Global
G	Topological	Geometry of a schematic is a valid reference to explain circuit's behavior	Global
Н	Closed circuit	Circuit is seen as a sequence of connected elements with two polarities/terminals.	Global
Ι	Ohm	Circuit is seen as a whole interacting system; electrical connections (series/parallel) are recognized	Global

Table I: Perspective coding schema for selected models adapted from literature about electric circuits

Code	Model Name	Description	Perspective
J	Block	Current/charge is blocked if it encounters a node/wire	Local
Κ	Opposite	Currents/charges of the same sign eliminate each other	Local
L	Ammeter focus	Ammeters are like batteries which distribute energy to other circuits' elements	Local
М	Elements	Circuit's behavior depends only on its elements, no matter how they are connected	Local
Ν	Subdivisions	Circuit's global behavior is the result of the superposition of independent smaller parts	Global
0	Functional	Circuit's behavior is recognized in term of elements' state	Global

Table II: Perspective coding schema for new models emerging from data analysis

Table III: Categories of answers not classifiable as models

Code	Category Name	Description
Р	Phenomenology	Explicit reference to relative brightness of the bulbs in the circuit is present
Q	No Justification	Quantitative answer is given but without justification

	Situation	1		2		3		4	5		6	7	8
Code			2A	2B	3A	3B	fellow	child	fellow	child			
A		1,2% (0%)			3,8%	3% (100%)					13,3% (0%)		13,6%
В		12,3% (0%)		11,5% (0%)	1,9%		6 3% (100%)	6 7% (33 3%)					
С				11,5% (0%)	15,1%							22,9% (0%)	
D				5,8% (0%)								10,4% (40%)	
Ε		8,6% (14%)	20,0%		7,5%	1% (0%)					25,5% (28%)		10,2%
F		6,2% (40%)	4,6%	3,8% (0%)	18,9%	4% (100%)	17,5% (100%)	15,6% (100%)	12,8% (80%)	11,0% (0%)		12,5% (83%)	1,1%
G			20,0%		1,9%	19% (0%)	19,0% (100%)	13,3% (100%)	20,5% (37,5%)	11,0% (0%)			
Н		14,8% (0%)	27,7%	9,6% (100%)	5,7%		11,1% (100%)	20,0% (88,9%)	38,5% (46,7%)	50,0% (67%)	15,3% (40%)	4,2% (100%)	38,6%
Ι		13,6% (9%)	6,2%	7,7% (100%)	18,9%	3% (50%)	9,5% (83,3%)		7,7% (100%)	6% (0%)		22,9% (100%)	3,4%
J					5,7%								
К				15,4% (0%)									
L		6,2% (0%)		3,8% (50%)									
Μ		5,0% (100%)	21,5%		15,1%			2,2% (0%)					
Ν		32,0% (4%)					36,5% (91,3%)	22,2% (100%)	17,9% (0%)	11,0% (0%)			
0													33,0%
Р					5,7%	5% (50%)		20,0% (100%)	2,6% (0%)	11,0% (0%)			
Q				30,8% (81%)		66% (27%)					45,9% (16%)	27,1% (100%)	

Table IV: Frequencies of PETs mental models for the situations presented in QELC. In brackets, the percentage of PETs who picked the correct answer when quantitative reasoning was requested (applies to situation 1-7)

Situation	1	2	2	3	3	2	1	4	5	6	7	8
Perspecti												
ve		2A	2B	3A	3B	fellow	child	fellow	child			
Global	56%	47%	10%	26%	20%	55%	30%	35%	15%	37%	18%	69%
Local	19%	13%	23%	20%	20%	4%	4%	0%	0%	12%	15%	11%
None	25%	40%	67%	54%	59%	42%	67%	65%	85%	51%	68%	19%

Perspective	PETs count	Situation	c.a. frequency (%)
nsistent: Global	15	1	12.5 (40)
sistent: Local	2	2	46.2 (50)
Mixed	54	3	26.5 (43)
None	37	4	92.3 (89)
		5	38.3 (32)
		6	20.4 (79)
		7	68.7

Γ

Appendix

Questionnaire on Electrical and Logical Circuits (QELC)

Situation 1. Look at the circuit in Figure 1. The bulbs are identical. Ammeter *A* measures *1.2 A*.

1A. Describe the circuit to a person who has to build the circuit but cannot see the scheme	
1B. Predict the values for Amp1, Amp2 and Amp3 Amp 1 :; Amp 2 :; Amp 3 :;	Figure 1

Situation 2. Look at the circuit in Figure 2. The two bulbs are identical. Batteries are different. Ammeter Amp2 measures 670mA

2A. Describe in words the circuit	ر بعر ()۳:
2B. Predict the values for ammeters Amp1, Amp3 and Amp4. Briefly explain your reasoning	۲ Fic
Amp 1 :;	1,15
Amp 3 :;	
Amp 4 :;	



Situation 3. Look a the circuits A,B,C,D,E in Figure 3





Situation 4. Look at the schematic diagrams A,B,C,D in Figure 4

Situation 5. Look at the realistic circuits A,B,C,D in Figure 5



Situation 6. Look at the realistic circuits A,B,C,D in Figure 6







Situation 8. Look at the schematic diagrams A,B,C,D,E,F in Figure 8. Write down, for each circuit, when the bulb is on. Briefly explain your answer



Figure 8

Secondary School Physics

Design, development and validation of a teaching proposal for energy: results from a pilot implementation

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Abstract

Learning about energy is recognized as an important objective of science teaching starting from the elementary school. This creates the need for teaching simplifications that compromise the abstract nature of this construct and students' need for a satisfactory qualitative definition. Traditional teaching approaches have failed to respond to this need in a productive manner. In an attempt to maintain consistency with how energy is understood in physics they tend to either provide abstract definitions or bypass the question "what is energy?", which is vitally important to students. We suggest that shifting the discussion to an epistemological context presents a means to overcome the difficulties inherent in introducing energy as a physical quantity. We propose a teaching approach, for students in the age range 11-15, which introduces energy as an entity invented in the context of a theoretical framework for explaining changes encountered in physical systems. This framework is elaborated in a progressive manner through the assignment of various properties to energy (i.e. transfer, transformation, conservation and degradation). Each property is introduced in a manner that highlights its contribution to the explanatory power of the theoretical framework. The paper outlines the rationale underlying this teaching approach and describes the activity sequence. It also reports findings from a pilot implementation with a group of students, which are encouraging with respect to the position taken in this approach. The paper concludes with a discussion of the implications for validating activity sequences and for teaching and learning about energy.

Introduction

Learning about energy is recognized as an important objective of science teaching starting from the elementary school (AAAS, 1993). This creates the need, which is more salient in the case of the upper elementary and lower secondary grades, for teaching simplifications that compromise the abstract nature of the concept and students' need for a satisfactory qualitative definition. Despite the fact that the topic of *energy* has received much attention in the science education research literature (Schmid, 1982; Warren, 1983, 1986; Duit, 1984, 1987; Solomon, 1992; Kesidou & Duit, 1993) it is the case that traditional teaching approaches have failed to respond to this need in a productive manner. In an attempt to maintain consistency with how energy is understood in physics they

tend to either provide abstract definitions or bypass the question "what is energy?", which is vitally important to students. The dominant approach in traditional science teaching is to introduce energy as the ability to do work (Driver & Millar, 1986). This approach usually begins with the definitions of force and work and tries to link work with energy as an abstract concept. The law of conservation of energy is introduced as a fundamental aspect of nature and much emphasis is placed on quantitative applications of this law in analyzing what are called energy problems. We believe that the early introduction of the conservation law and its widespread application for solving quantitative exercises, (a) blurs the definition for students and, (b) instead of highlighting its epistemological aspects tends to reduce energy into a meaningless bookkeeping algorithm constrained to the use of solving 'energy problems'.

We take the perspective that the question 'what is energy?' is of fundamental importance to students and to a large extent determines their ability to integrate this construct effectively in their learning pathway. This study reports on an attempt to develop learning materials on the topic of energy for students in the age range 11-15 years old. Our research rests on the premise that students need to acquire a qualitative, albeit scientifically valid, notion of the concept of *energy*, which can be elaborated progressively so as to become more quantitative and increasingly aligned with scientifically accepted ideas. In view of the various difficulties that are inherent in introducing energy as a physical quantity we suggest that the discussion could be usefully shifted to an epistemological context.

The proposed teaching approach seeks to introduce energy as an *invented* entity in the context of a *theoretical framework* for explaining changes encountered in physical systems. The sequence of learning activities is organized in three sections. The first includes two case studies from the history of science; Aristotle's notion of violent and natural motion and Lavoisier's caloric theory. These are accompanied by activities targeted at helping students to (i) differentiate between observations, theories and models, (ii) appreciate the role of each in science and (iii) recognize how they are connected. The emphasis is placed on guiding students to appreciate the idea that in science we often build models and invent theoretical ideas in order to describe, interpret and predict phenomena. The second section promotes two main objectives. The first includes helping students appreciate the value of a single framework that could be used to explain the functioning of very different systems. The second relates to the introduction of energy as a construct that could serve such a unifying role. The discussion related to the latter objective is embedded in the epistemological context that has been formulated in the first section. In particular, energy is introduced as a hypothetical construct in the context of a theoretical framework, which has been invented in science because of its facility to provide a common

account for the various changes that are observed in systems, regardless of the domain they are drawn from.

The remaining part of the activity sequence elaborates the theoretical framework of energy in a gradual manner. In particular, students are guided to progressively develop the various properties of energy, namely transfer, form conversion, conservation and degradation and to appreciate how each contributes to the interpretive, descriptive and predictive power of the theoretical framework. For instance, they are guided to appreciate (i) energy transfer and form conversion as a class of mechanisms, which can be used to account for changes occurring in physical systems, (ii) energy conservation as a constraining condition that prohibits certain changes, and (iii) energy degradation as a property of energy, which allows predicting the evolution of processes in time. Students are also guided to develop the energy chain as a model that could be used to graphically describe the energy transfers and form conversions that relate to a given system that is under consideration. Figure 1 provides an example of an energy chain, and also a verbal description, that relates to the system of a mass and a spring. Students are guided to use this model as a means to apply the theoretical framework of energy to a physical system of interest and derive a qualitative analysis, in terms of energy transfers and form conversions, that relates to the operation of that specific system.

Methods and Sample

The sequence of the learning activities has been implemented in the context of a computer/science club. Participants were 28 students in the age range 11-14 years old who volunteered to take part. Students met with the instructors twice a week for 1,5 hours over a period of six weeks. During the teaching intervention we assessed students through two openended tests, which were administered before and after the teaching intervention. The first (Figure 2) pertains to students' understanding of the model of energy as a cause for changes in systems drawn from diverse phenomenological domains. In particular, students were presented with physical systems demonstrating a certain change and in each case they were asked to come up with a single explanation that accounts for a couple of changes. The test consists of two parts. The first part was administered before and after the teaching intervention while the second part was only given as a post-test. The second test pertains to students' ability to provide accounts of the energy transfers and transformations in order to analyze systems and describe the changes they undergo. In this test students were presented with two physical systems and in each case they were asked to describe the "trace" of energy. The first system included a worker using an electric drill to perforate a wall and the second showed a woman striking a ball with a golf stick.



The elastic potential energy that is initially stored in the spring is converted into kinetic energy. As it uncoils, the spring pushes on the mass and it transfers energy trough mechanical work, which is then stored in the form of kinetic energy of the mass.

Figure 1. An example of energy chain

Results

Data were exposed to phenomenographic analysis (Marton & Booth, 1997) in order to discern categories of responses. The categories relevant to the first task are illustrated in Table 1 while Table 2 shows the percentages and frequencies of students' responses across these categories in the pre- and post-tests.



Figure 2. Task for the model of energy as a cause of changes

As shown in Table 2, the number of responses that relied on energy transfer and transformation as a common explanation for the changes was significantly higher in the post-tests and this is encouraging as an indication of students' ability to analyze changes in terms of energy. Students' responses to the second test were evaluated with respect to their accuracy and comprehensiveness. Prior to the intervention, none of the students was able to effectively analyze the systems in terms of energy transfers and transformations. Most of the students (approximately 85%) constrained themselves to only citing the objects they considered relevant to the energy chain in both systems. For example, a common response in the case of the electric drill system is that "*energy goes from the plug to*

the drill". Other students provided irrelevant responses such as *"the drill will perforate a hole on the wall*" and only a small number of students referred to energy transfer (e.g. student 4 in Table 3). Also, most of the students stated that energy will disappear or will be used up during the processes taking place in the systems. After the teaching intervention, most students were able to provide accounts for energy transfer and transformation in both systems. In addition to this, most students recognized that energy will not disappear when the process will be over and that it will be stored in the surrounding air in the form of internal energy. Table 3 compares typical pre- and post-test responses from four students.

Description of Response	Typical student response
Energy transfer & transformation	In both cases energy that is stored in the system is transferred to the blades and this makes them spin.
Energy (vagueness)	The blades of the windmill spin because of wind energy and the blades of the electric motor because of the energy in the battery.
No common explanation	The blades of the windmill spin because of the wind and the blades of the electric motor spin because of its connection to the battery.
Force	In both cases the blades rotate because of force; the force of wind and the force of battery.
Irrelevant responses	The blades spin because something makes them do so.

Table 1. Categories of Responses

Despite the noteworthy improvement in students' ability to analyze systems based on the mechanisms of energy transfer and transformation, there are two issues that warrant further attention. First, even though some of the students could undertake a detailed and systematic analysis of the systems in terms of the mechanisms of energy transfer and transformation (e.g. student 4 in table 3) most of them tended to constrain themselves to only describing a small portion of the energy chains (e.g. student 2). Second, students' responses varied with respect to their accuracy and many students tended to yield to fallacious ideas. Their fragile understanding of energy degradation and energy as stored in systems rather than in isolated objects (e.g. in the oxygen-fuel system)

	Part A Pre-test		Par Post	rt A '-test	Part B Post-test	
	N	%	N	%	N	%
Energy transfer & transformation	2	9	15	58	18	69
Energy (vagueness)	6	27	2	7.5	1	4
No common explanation	10	46	5	19	3	11.5
Force	4	18	1	4	3	11.5
Irrelevant responses	-	-	2	7.5	1	4
Omitted Response	-	-	1	4	-	-
Total	22	100	26	100	26	100

Table 2. Categorization of students' responses in the pre- and post-tests

and also their tendency to identify mechanical work with force present conceptual difficulties that were prevalent in their responses.

Implications & Conclusions

Our data suggest that the curriculum materials designed in the context of the project EKTEMA can help students develop the model of energy as a cause of changes and make appropriate use of the mechanisms of energy transfer and transformation in analyzing systems. However, despite the promising results from data analysis, there is an important issue to address, which is currently under consideration, in the possible revisions in the sequence of the learning activities that could further enhance students' conceptual understanding and help them overcome persisting conceptual difficulties. 1 **Pre-test response:** *Energy is transmitted from the wire to the drill. When the process is over, energy will be spread to the air.*

Post-test response: The energy chain begins with chemical energy from the plug. Energy is transformed to electrical energy in the wires and to kinetic energy at the drill. Sound and heat will be transferred to the environment and they will end up as internal energy. When the process is over, energy will be transferred to the environment (internal energy) through heat and sound.

2 **Pre-test response:** *Energy goes from the plug to the drill. The energy makes the blades rotate and perforate a hole on the wall. When the process is over, energy will disappear.*

Post-test response: Energy is transferred to the drill through the wires. The drill then starts to function and it perforates a hole on the wall. When the process is over, energy will be transferred to other parts of the system increasing the energy already stored in them. Energy will not disappear.

3 **Pre-test response:** *Energy will be transferred from the man to the drill. This causes the drill to rotate and to perforate a hole on the wall. Energy is used up during the process.*

Post-test response: Electrical energy is transferred through the wires to the drill, which starts functioning and perforates a hole on the wall. When the drill is rotating there is also sound and heat. When the process is over energy is not lost. It is stored in the environment in the form of internal energy.

4 **Pre-test response:** *At the beginning, energy was stored in the stick. The energy was then transferred to the ball which started to move.*

Post-test response: Energy is initially stored in the woman and the oxygen in the form of chemical energy. When the woman strikes the ball, energy is transferred to the ball through mechanical work. A part of the energy that is transferred to the ball is converted into kinetic energy and the remaining part into heat and sound and it is transferred to the air.

Table 3. Categorization of the students' responses in the pre- and post-tests

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University Physics

A studio-classroom course on Electromagnetism

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Abstract

The first year bachelor courses "Waves" and "Electromagnetism" at the University of Amsterdam (UvA) are given in the studio-classroom format. We outline the structure of the electromagnetism course and discuss some experiences as (studio-) lecturers. To actively involve the students during the sessions, the course contains a mix of illustrative slides, animations, in-class demonstration experiments, web-based exercises with automatic feedback and laboratory experiments. The course is well received and the studio-classroom format appears beneficial for many students

Introduction

Research over the past decade has shown that modern education models that employ interactive teaching increase learning significantly (see [1]). The studio-classroom concept aims at interactive teaching and learning by a combination of standard lectures and traditional exercise sessions, using computer technology intensively. The traditional lecture room is replaced by a classroom (see pictures below) with the facility to present a (short) lecture and is configured such that students can work on exercises with the possibility to use a computer.





The problem with traditional teaching is the passive role of the students sitting in the large lecture rooms with a lecturer speaking for two hours or so. After some time, usually the student's attention fades away, resulting in a large discrepancy between what is taught and what is actually learned. The studio-classroom concept aims at improving this by activation of the students.

The first year bachelor courses "Waves" and "Electromagnetism" at the University of Amsterdam (UvA) are given in this format. Besides

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illustrative slides, animations and in-class demonstration experiments, the web based exercises play an important role. The primary goal of the, also integrated, laboratory experiments (practicum) is to contribute to understanding the theory. In this paper we outline the structure of the electromagnetism course, present our experiences and discuss the results of a questionnaire.

Course Electromagnetism

The lectures are presented in an interactive manner by raising questions about demonstration experiments, computer animations or a specific problem to ensure the students remain engaged. During the sessions, the exercises are mostly based on physics problems to solve with pen and paper. A substantial number of web-based exercises embedded in Blackboard (see [2]) with automatic feedback enables the students to work, interactively again, outside the sessions. Collaboration and discussions during the sessions is encouraged, while the lecturer and an assistant are always present and circulate to ask and answer questions. The 'transmission line' between lecturer and student is short, always open and above all bi-directional.

Course setup

The course consists of a total of 19 sessions of 3 hours each and represents 7.5 EC. Three main physics topics are discussed in the following order:

- Electrostatics (8 sessions of which 2 laboratory experiments),
- Magnetostatics (6 sessions of which 2 laboratory experiments),
- Electrodynamics (5 sessions of which 3 laboratory experiments).

The final exam is a combination of homework (25%), lab reports (25%) and two standard tests (50%), weighted as indicated.

A typical session is structured in the following way:

- 1. discuss topics/problems previous lecture (sometimes by student), 15 min.
- 2. lecture (demonstration, questions, discussion), 30 min.
- 3. example and/or work out a problem together, 15 min.
- 4. students make exercises, 30 min.
- 5. repeat 2,3 and 4 once.
- 6. At home or during session: web-based-exercises (Blackboard).

The course is developed with the help and advice of the Amstel Institute (see [3]) of the UvA.

Laboratory experiments

The primary role of the lab work in our course is to illustrate the theory. Naturally, in addition the students obtain experimental skills and get experienced in writing reports. For logistical reasons, the lab experiments fill a complete session and take place in a dedicated room. The students have to conduct two types of experiments, which we call 'short' and 'long':

- The short experiments take typically one to two hours. These experiments usually directly illustrate electromagnetism as taught in the lectures and more or less enforce the students to study the theory.
- The long experiments take a full session. These are mostly great classical experiments, simplified for first year physicists.

The table below lists the available experiments, separately for the two categories.

Short experiments	Long experiments
Plate-capacitor	Millikan (electron charge)
Cylinder-capacitor	Polarization of light
Mirror-charge	Michelson (interference)
Torsion balance (Lorentz force)	
Toroid magnet with slit (measurement with Hall sensor)	
Solenoid (with and without core)	
Magnetic induction	

An example of the studio mix

We consider as an example the lectures (see [4]) on static magnetic fields and especially the Hall effect. As an illustration of the theory we included a lab experiment that involves a measurement of a magnetic field with a Hall sensor. Various exercises are dedicated to this subject. Furthermore, we use a (self-made) computer animation (see screen-shot below) to get the students familiar with the Hall effect. The animation visualizes a current of negative (or positive charge) carriers and the induced Hall potential is shown. The students have to use the animation to answer some web based questions (and thus not just 'play' with the animation).

Note that the lab experiment illustrates the theory, while the lectures and exercises are a preparation for the lab work. This synergy is a very relevant advantage of the studio-classroom concept, because many students nowadays don't prepare much: just 'being 21' is already a full time job!



Increased learning?

It is difficult to judge, based on a single course or two, on whether the studio-classroom format improves learning. For that we have to rely on the positive conclusions of the aforementioned educational research. We summarize here our findings that apply to our course without the intention to make general statements. First of all, the atmosphere during the sessions is excellent, especially during the concluding poster session that really triggered the students. Since the start of the course in 2001, on average, 45 students apply the course each year. The overall exam success rate reaches 75%. Furthermore, the success rate approaches 100% for those students who attend all sessions, make exercises and hand-in homework. This group comprises about half of all students.

Before we discuss the results of a questionnaire, we wish to remark that in our opinion especially the (sub)average students benefit most of the studio-classroom format. The student is confronted with the theory at least twice and often more (i.e. interactive lectures, exercises, experiments) which allows to gradually grasp the big picture. Note that the information density is not high, but the information diversity is. This could be a problem for excellent students that can handle more information in a faster way. Finally, the studio teaching is reasonably intensive, both for the lecturers as the students.

Questionnaire

According to a study performed in the university-year 2004/2005 based on a questionnaire, the students find the lectures very interesting as shown in the table below (the percentage represents the students who answered in the affirmative). Remarkably, most students appreciate when the lecturer slowly goes through the slides and uses the whiteboard to work out examples. This is somewhat in contrast with the studioclassroom principle, which aims at a more active attitude of the students.

Sessions	Yes
Electromagnetism is interesting	90%
The lectures are interesting	95%
The lecturer should go briefly through the slides, such that I	
can start quickly with exercises.	30%
I like it/understand stuff better when the lecturer occasionally	
uses the whiteboard instead of slides.	95%

The laboratory experiments are no so well appreciated according to the table below. During the lab sessions, not all students are enthusiastic. It is necessary to convince the students that they cannot just believe everything that is written and have therefore to measure and so check theoretical predictions themselves. Above all, there wouldn't be physics in the first place without experiments. However, the students affirm that lab experiments contribute to their understanding of the theory. Obviously, to achieve this purpose the lab experiments should physics-wise connect to the lectures as much as possible.

Lab Experiments	Yes
I find lab experiments challenging	70%
I obtain practical skills	100%
I learn to critically interpret measurements	85%
Lab exp. contribute understanding the theory	90%

Conclusions

We developed a studio-classroom course on electromagnetism which comprises lectures, demonstrations, animations, web-based exercises with automatic feedback and lab experiments. The studio-classroom format allows interaction with the students and so keeps the student actively involved during the sessions. The course is well received and the power of the studio-classroom mix appears beneficial for many students.

Innovativeness

Experience with the full integration of lectures, demonstrations, animations, web-based exercises with automatic feedback and lab experiments in electromagnetism teaching is sparse. The presented course on electromagnetism is the first course in the studio-classroom format in the physics bachelor at the UvA.

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<u>http://www.ciue.rpi.edu</u> (the webpage of the Anderson Center for Innovation in Undergraduate Education of the Rensselaer Polytechnic Institute)

- [2] Blackboard is a commercial software package to create a web based learning environment. http://www.blackboard.com.
- [3] The Amstel Institute is the educational research center for beta-sciences of the University of Amsterdam. <u>http://www.science.uva.nl/amstelinstituut/home.cfm</u>.

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Development and Evaluation of an Activity- and Tutorial-Based Learning System for Students in Modern Physics at the University of Munich

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Abstract

Most of the time university lectures do not show success and effectiveness given the time that students spend learning. Therefore to remedy these and other defects at the Ludwig-Maximilians-University of Munich an activity-based learning-system for the introduction of Modern Physics has been designed. During the development cycles it has been tested and improved continually.

During the lessons the students work alone or with a partner on a multimedia enriched text, on problem solving and on interactive experiments. So the lecturer's primary responsibility is to organize the lecture and to act as an advising tutor. Most of the participating students will become teachers for secondary school (grades 5-10). The learning-system is used in a lecture called "Physics of Matter" which spans two semesters each with 6 hours per week. The learning-system has been evaluated using a comparative design. The empirical research regarding knowledge gain, concept development and attitudes show the following results: The students achieve a definitely higher learning success than in traditional lectures.

The learning time during the lesson is sufficient – additional homework is not necessary. The students enjoy the climate in the class.

Reasons for the Learning System

The development of the Learning System at the University of Munich started with the following question:

How could students' work during a typical lecture be characterized? An interview study, showed the following results:

• During a traditional lecture students are occupied by transferring information on the chalkboard

- Gaining knowledge takes place after the end of lectures, i. e. at home.
- Students invest in no regular out-of-class studying but start intense learning shortly before the exams.

To increase the lessons' effectiveness the Learning-System has been developed. The priority of that system is to support the endeavor of students as well as self-controlled learning behavior. A supporting climate of maintaining higher skills of learning should be generated as well.

Particular Characteristics

During the lesson the participating students work within the Learning-System in an individual way or in peer groups on a multimedia enriched text, on problem solving and on interactive experiments. So, the lecturer's primary responsibility is to organize the lecture and to act as an advising tutor.

That course is addressed to students of physics as a subsidiary subject and to students who will become teachers for secondary school (grades 5-10). The Learning-System is used in a lecture called "Physics of Matter" which spans two semesters each with 6 hours per week (in a traditional way four lessons per week as a lecture, and the residual two lessons as practice). The lecture introduces Modern Physics including quantum physics and particle physics with the theory of relativity in the first semester. The second semester includes nuclear physics and solid-state physics.

Particular characteristics of the Learning-System are:

- Active learning supported by the tutor
- Learning with multimedia
- Cooperative learning

The students achieve knowledge during the lessons by reading, discussing and working on problem solving. The tutor gives support to the students. With interactive multimedia elements the student's activity will be increased.

Cooperative behavior will be supported to maximize the success of learning. By cooperative learning the students will be motivated by belonging to a cooperative group [Burge, Rogerts 1993] as well as by processing of content of teaching [Dansereau 1988].

Elements

The elements, which are included into the Learning-System, are:

- short lectures
- basic texts
- controlling questions
- exercises
- a web-based course with multimedia elements

The short lectures include tutorial briefings, summing-ups and introduction of discussions. The students read the basic texts during their lessons in an adequate time frame. After that they try to solve the key questions, which are questions taken from the text. This happens in groups. The exercises are worked on and discussed at present, contrary to a traditional lecture, in which the exercises must be worked on as homework.

The web-based course follows the chapters of the basic texts. It contains integrated multimedia-elements like java-applet-experiments and

animations. The experiments are performed in group work and the results are discussed together with all members of the class.

The materials have been developed during the past three years, especially for participants of the course "Physics of Matter", tested in the class, evaluated by the participants and also improved continually in every cycle of evaluation.

You will be able to find the whole original course at the webpage: <u>http://www.cip.physik.uni-muenchen.de/~traupel</u>

Design of Evaluation

Two criteria of the evaluation needed to verify the learning-efficiency [Issing, Klimsa 2002] are:

- the acquired knowledge
- the students' acceptance.

The data had been recorded by

- learning tests
- interviews
- questionnaires.

The efficiency of the new method of teaching was tested by a comparative design between the traditional education and the Learning-System. The comparative design includes the comparison within

- a group of students (various subjects)
- a subject (different groups).

The results are shown in Table 1.

The participants of 2004th summer semester had been taught by a lecture at first and after that by the Learning-System. This structure gets along with contents, because two subjects are taught during the summer semester: quantum physics at first and particle physics after it. A learning test after every stage assesses the gain of knowledge.

This kind of comparison within a group having different subjects is not adequate. Maybe particle physics had been easier to the students than quantum mechanics. On that score a comparison within the subject must be made. That implies, that particle physics is taught in summer term 2005 to a new group of students once again using the method of traditional lecture. That gives us the possibility to compare both methods of teaching in relation to the subject of particle physics and to compare the criteria of evaluation.

Also, quantum physics was taught in the summer semester 2005 once again with the Learning-System. So it is possible to draw comparisons within the subject quantum physics and once more within the group of students in the summer semester 2005. *The configuration of lectures was modified in one way.* The required exercises, which had been made to complement lectures, were completed by the students during the class (like the Learning-System). It had to be done in such a way in order to guarantee that the participants of lectures had the same workload as the participants using the Learning-System while working through the same subject. This modification has probably an effect on

- the learning success
- the climate in the class.

Results - Learning Tests

Assessments have been made in terms of written learning tests with usual length of 45 minutes. The learning tests within the same subject were identical for both tested groups of students.

The average percentages of all points that could be achieved by students on each learning test are presented below:

Semester	Subject	Method of education	Result
SS04	quantum physics	lecture	26%
SS04	particle physics	Learning-System	63%
SS05	particle physics	lecture	35%
SS05	quantum physics	Learning-System	61%

Within a group the comparisons show significant learning success for both groups of students in the summer semester 2004 and the summer semester 2005. Making comparisons within a subject like quantum mechanics shows greater learning success using the Learning-System. Likewise a similar comparison is seen in the subject particle physics. The comparative design shows the dominance of the Learning-System over the method of a traditional lecture.

Results - Acceptance

The results regarding the second criterion of evaluation -- the acceptance by students – are also important. The interview study shows how students estimated their perceived learning success plus climate during lectures and while working on the Learning-System.

Students estimated their learning success during the lectures of "Physics of Matter" at high level, higher than in any other lecture they know from

their studies. Also the climate during the lectures of "Physics of Matter" evaluated very well: Students said that it differs substantially from any other lecture they knew. The general climate during typical traditional lectures is characterized as a passive one. The relation between lecturer and students is aloof.

Students are inhibited to ask questions. And there are no realistic possibilities of interaction between students and lecturer.

On the other hand students rank the ambiance during lectures of "Physics of Matter" as very pleasant and so it reinforces for learning.

Students name the following reasons for their attitudes:

- Communication and cooperation during the exercises
- Openness for questions
- Small distance to lecturer

The self-assessment of students during the Learning-System about the perceived learning success is very high (that agrees with the results of the learning tests). The ambiance was rated at a higher level, too. The following reasons are mentioned:

- More communication between students
- Higher motivation, because students notice the gain of knowledge

The main differences between the Learning-System and a traditional lecture are as follows

- Active learning
- Notice of individual learning success
- Communication with lecturer

Summary

The aims of the Learning-System have been achieved. The effectiveness of the lecture could be maximized. Working time of most participants is limited to the time frame of the lesson. The acceptance of the Learning-System by the students is high. The students enjoy the learning climate in the class.

The scale of acquired knowledge is much higher for students in the Learning System than for those in traditional lectures as the comparative design shows. Therefore the Learning-System shows a higher efficiency of learning. For a complete description of the development and evaluation of the Learning System see [Traupel, 2006].

The use of this conception for teachings at universities should be integrated into all course. The German Physical Society (Deutsche Physikalische Gesellschaft) postulates a new conception of education of teacher's next generation in physics [DPG, 2006]. The Learning-System seems to be predestined for it.

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Teacher Education

Explicit Modelling in Guiding Student Teachers in their School Practicum: A Self-Study of Student-Teacher Oriented Teaching

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Abstract

If teacher educators wish to educate physics teachers to teach in a student-oriented way, they themselves should teach their prospective teachers in the same way. This modelling should be done explicitly so as to stimulate the prospective teachers to reflect on their way of teaching. An important event in the education of a student teacher is the visit of a teacher educator during a lesson in the internship school. This paper reports about a set-up of a school practicum visit, as a result of a self-study from the perspective of student-teacher-orientedness.

Loughran *et al.*, 2004 have plead for self-study (action research) of teacher educators on their own teaching. This appeals to me, and in this paper I want to reflect on one of my tasks as a physics teacher educator: the visit to student teachers' school practicum lesson.

I started the self-study when I specified 'making student teachers more student-oriented' as the main goal of my lesson visits. I wished to explicitly apply the congruency principle (Korthagen *et al.* 2001): if I want the student teachers (STs) to teach in a student-oriented manner, I must supervise in a student-oriented manner. The issue of this study was: how to set up a lesson visit more student-teacher-oriented, so as to make student teachers more student-oriented?

Student-oriented science teaching means giving students the opportunity to put their thoughts and meanings into words and actions. For this, mastering the subject teacher role is crucial to a teacher. This especially goes for teachers in physics, because they will inevitably run into problems with concept development (Driver *et al.* 1985): how do you provide students with insights into the meaning of concepts such as energy, force, and particles?

When STs start teaching in a student-oriented manner, they will encounter unexpected problems. Fathoming and supervising the concept developments that their students go through demands a thorough insight. STs may discover that they themselves run into conceptual problems as well (Frederik *et al.*, 1999). Moreover, it is difficult to integrate knowledge of misconceptions in the teaching practice. It is necessary to embed this knowledge in the context of the actual teaching ('situated cognition', Putnam and Borko 2000). Lesson visits by physics teacher educators may provide a well suited opportunity for this embedment.

Approach of the self-study

I have always worked well with a more or less intuitive set-up of the teaching practicum visit:

- making an appointment with the student teacher and the mentor in the school
- observing in the classroom, making notes
- having a review discussion
- making a short report.

My aim that resulted in the self-study, exploring how to promote STs to teach student-oriented, made me feel more and more uncomfortable with that set-up. Therefore, I started adding new elements to my set-up, e.g. asking STs to make a report of the review discussion.

I have tried out single elements during various lesson visits. In my lesson visits to one student teacher, G., I implemented all of them and reflected on the experiences. To record the process, I collected my notes of the observations and the review discussions and I wrote down my reflections. I draw, with his permission, data from G's digital portfolio. I presented the results to my colleagues of IVLOS and processed the remarks they made.

Results of the self-study

The main result of this self-study is the revised set-up of my lesson visit to the teaching practice of an ST. It consists of four parts:

Preceding the visit

- 1) Appointment with the student-teacher (ST): the ST informs the school supervisor and also invites him/her to the afterward discussion.
- 2) Request: send me a lesson plan, as well as observation cues.

During the visit

- 3) Before the start of the lesson: short interview with the ST
- 4) During the lesson: observations; no interventions
- 5) At the end of the lesson: short interviews with a few students.

The review discussion

6) The review discussion takes place directly after the lesson if at all possible. In it, at least the observations related to the cues are reviewed and classroom events related to different teacher roles are discussed

The report

7) ST makes report of the lesson and review discussion

8) I give my reaction to the report and if approved, the ST takes it up in the digital portfolio.

Below I shortly describe the importance of these parts. I illustrate my points with examples from my visits to G.'s lessons.

Activities before the visit

Before my first teaching practicum visit to G., I agreed with him about the day and time of the visit. I asked him to announce my visit to their mentor teacher and to invite him to take part in the review of the lesson. Furthermore, I asked him for his lesson plan. G. handed it to me just before the lessons began.

Reflecting on this afterwards, I realized that, from the point of studentteacher oriented teaching, I had to know what G. had wanted me to observe in his lesson. I was ill-prepared for the observations. Therefore, when arranging the second lesson visit some months later, I asked G. to send me his lesson plan as well as observation cues for me, making explicit that I wanted to contribute to the points he wanted to learn about. The lesson plan and the cues proved to be very useful to gear our expectations about the lesson visit on each other.

Interview just before visiting the lessons

At the start of the first lesson visit to G. there was little time for talking. On our way to the classroom, I asked G. to introduce me shortly to the class.

Reflecting about this, I realized that I had not been explicit why I wanted with the introduction. That is needed to prevent that students become distracted by my presence ('what does this guy have to do in the classroom?') Moreover, I realized that G. did not know at all what I planned to do in the classroom. That might have made G. feel unsafe. In my second visit, I had an interview with G. just before the lesson. I explained what he could expect me to do in the classroom, to be as discrete as possible and make no interventions. Moreover, I asked him for permission to have some short interviews with students after the end of the lesson.

Observation cues

The first time I observed G., he started with a classroom discussion on nuclear fission. Next, the class was split up in groups. Each group studied some specific nuclear fission situation, made a poster about it and presented it to the class. It was the first time G. used posters in his lesson. He had planned this poster lesson in order to get my feedback, but I did not know! I concluded that I had to ask students for observation cues. My second time in G's lesson, I knew that G. wanted me to observe, among others, interaction with the students. Preparing myself to this

lesson visit, I read in G.'s in-between portfolio that had been occupied with the question:

How do you go about half-correct answers? This is the question I still ask to myself, because this came up during my first teaching practice. Students did not feel rewarded and this can be demotivating.

This question we had discussed after the first lesson visit, as then he had rewarded right answers and had rejected answers that were not fully right, but that did show some insight. In my observations during the second lesson visit I noticed that he had solved that concern. He promoted students explaining their views on air pressure, accepted incorrect and half-correct answers and brought those in a classroom discussion. The cue G. had given me, had been very useful!

Short interviews with students

Being student-teacher oriented, I should exemplify getting feedback from different sources and ask the students about their experiences with the ST's lesson. So, before my second visit, I asked G.'s consent to talk to some of the students after he had ended the lesson.

I asked a couple of students questions like 'What did you like about this lesson?' They automatically drew this on to G.'s teaching and expressed their contentness. They felt the atmosphere was good and G. always answered their questions. This asserted my observations and gave me some points for the review discussion.

The review discussion

After my first classroom observations, we started the review discussion by making up the agenda. G. wanted feedback about the poster presentation and about his interaction with students. I asked him to start reflecting, from which I led on. I told him that during the lesson he awarded many students, and also that he rejected right away the answers that he found incorrect, even if they were partly correct. G. admitted that he did not know how to encourage students who do not give a fully correct answer. I gave him some suggestions about how to do it more efficiently.

Reflecting on this, I found what I had done was fairly student-teacher oriented, but I felt that I was not explicit enough why I did so. In the second visit, I elaborated the procedure and made it more explicit:

- a. I explain the structure of the review discussion, including making notes and reporting.
- b. The ST gets the opportunity to give his first impressions.
- c. Together, we select some aspects of the lesson to be reviewed:
 - the observation points;
 - other points resulting from teaching or observing the lesson;
- d. The review discussion is started: the ST is first given the floor, then the observers.

e. The ST formulates conclusions and new intentions.

G. was content with his lessons and with the interactions with the students. I confirmed that and told him that his students liked his lessons and that it was typical for the atmosphere in his class that the students felt free to bring forward their correct, half-correct and incorrect answers. We discussed what he exactly did: inviting students, taking their answers seriously before indicating which ones are correct. We concluded that this approach contributed to the safe atmosphere during the lessons. I told that I had heard some misconceptions during his class on air pressure. He had remarked one and described some more. Reflecting on the review discussion, I concluded that G. had learnt to be student-oriented and had become sensitive to student thinking.

ST's report of the review

In the report G. wrote after my first lesson visit, he shortly mentioned the discussed points with the poster presentation as a special point of attention. It showed that G. had learnt about student-oriented teaching and that he had started making a connection between rewarding, using interactive working forms, and responding to student contributions. The report he made after the second visit showed that he was happy with the review discussion, in particular about a discussion we had on students' misconceptions:

During the lessons many misconceptions of students came to the fore that deeply impressed me. Ton related many of those notions to the literature, and this inspired me to read through the literature on misconceptions myself. Also, it is starting to get to me how important working methods are for a good student-teacher relationship.

The making of a report of the review discussion by G. had several positive effects. G. had to actively get busy and became 'owner' of the result of the lesson visit. That enhanced the learning effect. The report gave me insight into the progress of G. I received feedback on my lesson visit. Because I thought it was a very good report, I reacted by naming some strong points in his development.

Discussion and conclusions

Lunenberg and Korthagen (2005) have found that the teacher educators from their research group did not sufficiently succeed in providing their students with a student-oriented 'mental model' of education. Such a model should provide an alternative to reverting to the traditional way of teaching that STs undergo themselves as school students. Teacher educators especially lack in three areas:

- Attention for personal interest-oriented learning of STs.
- Varying in ways of reflection.
- Discussing educational choices with the STs.

In my set-up a lesson visit is an opportunity for paying attention to personal interest-oriented learning of STs: asking for observation points; using these points when making the agenda for the review discussion. It is important that I, reacting on ST's report of the review discussion, demonstrate clearly that I have observed and appreciated the ST's individuality.

The set-up provides for varying ways of reflection at different times:

- beforehand through thinking of observation points
- afterwards through the review discussion
- reflection on the review discussion itself by making the report
- overall reflection by incorporating the results into the portfolio. The set-up offers room for STs to put their educational choices on the

agenda through sending the lesson plan and the observation points. The review starts with discussing these choices.

The set-up of a lesson visit developed in this self-study is student-teacher oriented. It provides an opportunity for promoting student-orientedness and making student-teachers experience it.

It is recommended to have student teachers carefully prepare the lessonto-be-visited, suggesting observation cues for the teacher educator; to start the review discussion with reporting about these cues and to ask student teachers for a reflective report about the lesson and the review discussion.

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Motivational Strategies

Developing Students' Interest in Physics Through the Use of Role-Play

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Abstract

This paper suggests role-play as a supplement to the traditional way of teaching science. The reasons for choosing role-play in science teaching are based upon student's interests and the competences developed through the use of role-play. The paper presents a brief introduction to the interest theory and the competences in play through role-playing along with a role-play example involving the Manhattan project and some empirical research results.

Introduction

Nowadays many people talk about a crisis in science. The crisis being that only few students are choosing to follow a career in science and in particular physics. In Denmark this has resolved in many changes in the educational system launched by a reform in 2005 in an effort to get the students more science minded. Now science plays a more dominant part in children's education especially at the upper secondary school level (Gymnasium) [1].

One of the reform changes involves the quantity of science taught to the students. At upper secondary level this results in more science teaching for all students regardless of their choice of stream and a basic level physics course is now mandatory for all students.

Another reform change is an increased focus on the students' identities and interests. One of the explicit ambitions of the reform is that science teaching needs to be more relevant and essential to all students and a criterion of success is to catch, hold and increase students' interest in science [2].

These reform changes have consequences at the teaching level as science and physics now needs to be presented to, and understood by, a larger and less homogeneous group of students with varying levels of interest in science which calls for new ways of thinking science teaching.

This paper presents some reasons for why role-play is useful in science teaching and how it affects the students' interest in science. This paper also presents a concrete example on how role-play can be used in science teaching.

1. Students' interest in science

Dewey stated in 1913 [3] that there is a strong connection between students' interest and the effort of their work. He also stated that if you catch the students' interest you are guaranteed their attention which is a good foundation for learning.

In the mid eighties interest research had a renaissance where researchers began to define the term *interest* and its connection with learning outcome in education. According to Krapp [4] and Hidi and Renninger [5] interest is to be seen as a relation between a person and an object where the object can be a physical object, an activity, a subject etc. In a teaching situation the object of interest is usually the subject itself or a specific topic taught and the activities in the class like for example group work or lab work are seen as the mediator for the object of interest. It is also possible to regard the specific activity used in the teaching as the object of interest and the subject itself as the mediator for interest which is suggested later in this paper with respect to role-play as an activity. Hidi and Renninger [5] categorize interest into four subsequent phases of interest: triggered situational interest, maintained situational interest, emerging individual interest and well-developed individual interest. In short the two phases of situational interest both refers to a psychological state of interest resulting from external parameters in the specific situation for example a teaching situation. Phase one refers to a shorttermed interest in for example a single lecture where phase two refers to a persistent interest over an extended period of time for example several days or weeks of lectures. The two phases of individual interest both refers to a psychological state of interest as well as a relative enduring internally driven interest.

The aim of the role-play related research in this project is to unravel students' interest for science when using role-play in the science teaching and the phases of interest examined in the project are the two first phases of situational interest and whether students' interest for science develops in the teaching.

2. Role-play in science teaching

In Denmark role-play has become a very popular leisure activity for young people over the last couple or years and role-playing is now more popular to young people than more traditional leisure activities like tennis or basketball [6]. This highly suggests that there are some aspects in roleplay that interest young people.

Role-play can be defined as a way of deliberately constructing an approximation of aspects of a 'real life' episode or experience, but under 'controlled' conditions where much of the episode is initiated and/or defined by the teacher [7]. More generally a role-play consists of three central elements: *a conflict* - the issue that causes a problem of some sort which needs to be discussed or resolved during the role-play, *a setting* in

which the conflict takes place, and *the roles* or characters that is played by the students.

In science teaching situations creating a role-play typically means creating scenarios that incorporates a scientific conflict of some sort which needs to be resolved by scientific experts or other involved persons.

As suggested earlier in this paper role-play might be a good mediator for interest or an object of interest in itself. Therefore creating a role-play for science teaching might be a good way of creating interest for science. Some elements that make it interesting to role-play are the experience of actively being part of a story or discussion and engaging yourself into the scenario.

When creating a role-play for science teaching it is important to be aware of the pitfalls associated with using educational games. The biggest problem is creating a role-play that is both interesting and educational at the same time so that the students also learn some science. A way of dealing with this problem is to incorporate the role-play as part of an educational program, playing the role-play at either the beginning of the program as an teaser for the content to come or at the end of the program as a highlight of the program.

A well made role-play-based educational program develops both the students' interest as well as many of the scientific competences. Gräber *et al.* [8] suggest a competence based model of scientific literacy including seven key competences needed for the students to cope with our complex world. The seven competences in their model are divided into *what do people know* including subject and epistemological competence, *what do people value* including learning, social, procedural, and communicative competence, and *what do people do* including ethical competence. In this context it is useful to use role-play to develop some of the competences which are normally undeveloped in ordinary science teaching like the communicative and the ethical competences.

When designing a role-play it is also important to choose a conflict that in some sense is relevant to the students in order to create a situational interest and personally involve and engage the students.

3. A role-play example

This section briefly²² presents an example of a role-play-based educational program called *Dramatic Science Play* developed for the lower and upper secondary schools in Denmark. It was developed as a collaborated work between two centers at the University of Southern Denmark²³.

²² A more thorough design description of the educational programme can be found in [9]

²³ DSP was developed in collaboration between *The Center for Science and Mathematics Education* – a center that strengthens the interplay in science between schools, university and industry and *The Centre for Art and Science* – a center that strengthens a dialogue between the world of research and the public by the use of artistic means.

The content of the educational program is the Manhattan project in relation to history and the society. As a consequence of this interdisciplinary nature of the content the involved subjects are physics, history and social studies.

The educational program is designed with the role-play in the end of the program. So before playing the actual role-play the students are first introduced to the physics, historical and social science facts needed to understand the setting and conflict of the role-play in a "classical" way of teaching. After the introduction the students work in groups preparing themselves for playing their characters. The students also prepare themselves for presenting some character-related subjects in the role-play. In their preparation the students use material which is both handed out by the teacher and posted on a homepage²⁴ created for the purpose. The setting of the role-play is two imaginary meetings at the White House at the end of World War II based upon the real meetings of the Interim committee. Here the students play nine of the persons involved in the development and use of the nuclear bombs who are all summoned by the president as his personal advisors. The characters in the role-play are divided into three categories being physicists, politicians & military figures and doctors, such as War Minister Stimson, General Groves, project leader Oppenheimer and physicist Fermi just to mention a few. Part one of the role-play takes place before the bombing of Hiroshima and here the advisors explain and discus how the nuclear bombs work, how to use them, and where to use them. The meeting ends with a letter from the president pronouncing his decision to bomb Hiroshima. Part two of the role-play is a second meeting several days after the bombing of Hiroshima. At this meeting some of the effects and consequences from the Hiroshima bomb are presented to the students and they now have to decide whether or not to bomb Nagasaki. This part is a contra factual part where the students have the option not to bomb Nagasaki.

The educational program is ended by a discussion and conclusion phase.

4. Methods and results

The educational program was tested in 10 lower secondary school classes and 2 upper secondary school classes.

In order to encapsulate and document changes to and development of the students interest a variety of both quantitative and qualitative research methods were used. The role-plays where observed and video recorded in order to observe possible traces of occurring situational interest. Some of the students were interviewed to get a closer insight in their interests and their experience during the role-play. All of the students answered a semi-open questionnaire containing 56 questions after completion of the educational program in order to get a broad overview and tendencies of

²⁴ Homepage for the educational programme in Danish: <u>http://www.dsp.sdu.dk</u>

all the students' interests. Furthermore data was collected from teacher interviews, classroom observations and student essays.

The empirical data has still not been thoroughly analyzed therefore this paper can only present some preliminary results whereas later publications will present the overall conclusions.

Many of the students expressed that playing role-play was a *new*, *a different*, *a fun*, *an exciting*, *a challenging and an interesting* way to learn, showing their engagement and interest in the role-play. Also one of the students commented "... *at the same time it suddenly becomes interesting to read and practice the material as it was necessary for preparing your role*" expressing in a clear statement how the active preparation to the role-play resulted in a situational interest. Another student expressed how being actively engaged in the role-play affected her interest in the teaching situation by writing that "... *it gives a greater interest when you get to participate yourself* ...".

In the questionnaire the students were asked how their interest for physics was after the role-play compared to before. It turned out that about 1/3 of the students experienced an increase in their interest in physics while the rest of the students interest remained unchanged. This result is taken very positive as the students were asked how their overall interest in physics had changed.

Conclusion

Role-play designed in the right fashion seems to be a possible way to develop and maybe increase students' interest in science and also enhance their learning outcome as the students become actively engaged in the teaching situation. The students' positive attitude towards role-play in the teaching suggests that role-play should be used as a supplement to ordinary teaching of physics and science in both lower and upper secondary school.

This being said it is also important to acknowledge the limitations and pitfalls when using role-play in science teaching and always stay focused on educational purpose and learning outcome when designing a role-play.

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Multi-Media in Physics Education

Different uses of ICT for modelling in Physics Education: three examples

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Abstract

This paper presents examples of applications of multimedia representations in compulsory school, high school and at undergraduate level. The aim is to enable students respectively to understand the critical features of the modelling process for optical phenomena, to explore and compare a rich variety of contexts related to collisions in mechanics, to highlight the role of thought experiments as arguments to infer the counterintuitive implications of the speed of light invariance in special relativity.

Introduction

Specific uses of various types of multimedia representations can support teaching strategies for overcoming students' learning difficulties in physics (Nancheva et al., 2005; Gagliardi et al., 2005). In particular the modern software offers a variety of powerful editing options: video/photo editing programs for working on single frames or frame sequences, drawing programs for producing detailed schemes and pictures, advanced 3D programs for accurately reproducing three-dimensional and photorealistic settings, etc.

In the following sections some applications to different physics topics are presented.²⁵

a. Optical phenomena

We will describe animations aimed at helping the students to understand the geometrical representation of optical phenomena by overcoming the difficulties both of visualizing 3D continuous light distribution in space and of connecting it to the discrete ray model and its 2D standard representation.

Examples are taken from the web site "Light and Vision" (<u>http://pctidifi.mi.infn.it/lucevisione/</u>), which was designed to help the K-12 teachers first to understand the concepts involved on their own and

²⁵ The animations mentioned in this paper can be found at the web address <u>http://www.df.unibo.it/ddf/GIREP06</u>.

later to guide their students in the modelization process in optics (Gagliardi et al., 2006).

The aim is to avoid the growth of many undesired (and often schoolproduced) alternative conceptions concerning the scientific interpretation of everyday experience (Viennot, 1996; Galili et al., 2000). The spontaneous sensation of a static "light-bath" fulfilling the entire space in which the objects that we can see are located has to be replaced with the idea of propagation and geometrical distribution in a 3D space that can only be imagined. We have attempted to visually reconstruct the process leading from perception of more or less bright spots to the reconstruction of 3D spaces of "light" and "shade". *Figure 1a* and *1b* show how the mental reconstruction of the light beam and the shadow cone produced by a point-like source was schematized.



Fig. 1. a) from the perception of light spots changing in size and brightness to the reconstruction of a not visible three-dimensional light beam; b) from the perception of a two-dimensional shadow changing in size and shape to the reconstruction of not visible cones of shade; c, d) intermediate steps for the comprehension of the interpretation/description of real source shadows as a superposition of shadows generated by a continuous distribution of ideal point-like sources.

Traditionally only point-light sources are described in geometrical optics. This approach disregards the perceptive effects due to real light behavior. A point-like source is a purely ideal object: only 3D sources exist in reality and the beams from real sources can be approximated by the point-like ones in specific cases only and from specific points of view. Nevertheless, a real source behavior can be reconstructed as superposition of a infinite number of point-like sources. This very feature of optics makes it a favorable context to enlighten the connection between ideal and real objects in physics, provided that students are able to make the transition between the two. The animation described in *fig. 1c* and *1d* aims at enhancing this step concerning 3D and 2D penumbra areas generated by real sources.

Figure 2 describes some examples of animations specifically designed to help students conceptualize and interpret ray representations usually adopted in geometrical optics.

b. Mechanical collisions

Computer simulations can be seen as having different aims:

- effective computer simulations are built upon "mathematical models" in order to accurately depict the phenomena or process to be studied;
- a well-designed computer simulation can engage the learner in interaction by helping the learner to predict the course and results of certain actions, understand why observed events occur, explore the effects of modifying preliminary conclusions, evaluate ideas, gain insight and stimulate critical thinking.

When using simulated laboratories it is important to keep in mind that reality is inevitably more complex than the virtual world. Therefore every student should be invited to try the real experiment whenever possible (in the school lab or at home) or to look at physical phenomena in a real context. Although simulated laboratories can be a powerful educational addition and complement to the traditional methods of physics education, they cannot substitute classical education (Min, 2002).

Our intention is to develop a multimedia product (interactive animation that allows data to be collected, represented and analyzed) concerning collisions among carts on a linear track.

The teacher will be able to use the animations in different ways for different teaching purposes. The data analysis will allow the students to construct the basic physics model from which further studies on interactions can be developed.



Fig. 2. a, b) three-dimensional reconstruction of Kepler model for image formation on retina (interactive animation); c) plain reconstruction of the relationship between the reflection of a whole light beam sent from a point-like source on a flat mirror and the virtual point vision; d) reconstruction of the images of three different point-like sources virtual images by a flat mirror.

The animations show a one-dimensional collision between two carts freely sliding on a track. In the virtual environment changes in several variables will be allowed: the linear momenta (by changing the carts masses and/or their initial velocities), the kind of collision (from elastic to totally inelastic collisions), the friction coefficient between the carts and the track.

This type of interactive simulation can offer different educational opportunities according to the different teaching goals selected by the teacher. For instance, the students can carry on the activities as they were in the real lab by collecting data from the two carts (position versus time) following a step by step analysis (*figure 3c, 3d*), elaborating data and formulating a phenomenological description which can lead to formalize and to discuss the linear momentum and the energy conservation laws. Moreover the simulated experiments with their "clean mathematical" data can act as a reference to be compared with either real lab experiences or other simulations, in order to emphasize the peculiarities of each context and to stimulate, as in the case of optical phenomena shown above, the students' reflection on the relationship between physical models and real phenomena.

c. Introduction to special relativity theory

A series of interactive animations illustrating Einstein's thought experiments about relativistic effects (relativity of simultaneity, length contraction and time dilatation) have been designed to provide the teachers with tools to stress some crucial issues that, according to research



Fig. 3. Elastic collision in an isolated system: the data collection during the phase of interaction.

results, are usually bypassed by the students who tend to preserve the classical conceptions of space and time (Grimellini Tomasini, Levrini, 2004; Sherr et al., 2001). In particular the following difficulties have been pointed out:

- accepting the counterintuitive relativistic effects (relativity of simultaneity, length contraction and time dilation) as a direct consequence of the postulates: the postulates are so easy to be learnt by heart that students tend to memorize them without recognizing their revolutionary impact on physics content knowledge (Posner et al., 1982);
- recognizing the relativistic effects as due to the *invariance* of the speed of light and, then, to the relative motion between frames of reference: "Many students interpret the phrase "relativity of simultaneity" as implying that the simultaneity of events is determined by an observer on the basis of the *reception* of light signals. They often attribute the relativity of simultaneity to the difference in signal travel time for different observers." (Sherr et

al., 2001). In fact, students tend to relate the relativity of simultaneity to the *finite* value of the speed of light, underestimating or misinterpreting the role of the speed invariance.

By visualizing Einstein's thought experiments, interactive animations can help the teacher to:

- stress relativistic effects as direct consequences of the postulate of the speed of light invariance (*fig.4*);
- problematize the concept of "observer" as receptor of light signals and stress length and duration as relations between *events* to be formalized by applying a well-defined measurement procedure in a reference frame (*fig. 5*);
- construct progressively the concept of space-time interval through a deep discussion of proper time and proper length as invariant quantities and open in the direction of stressing what Born considers one of the main results of special relativity: "quantities regarded by the older theory as invariants, like distances in rigid systems, time intervals shown by clock in different positions, masses of bodies, are now found to be *projections*, components of invariant quantities not directly accessible" Born, "Physical Reality", 1953 (*fig. 6*).



Fig. 4. The relativity of simultaneity animation and the role of the speed of light invariance.



Fig. 5. The length contraction animation and the definition of length of a moving body.



Fig. 6. The time dilation animation and the definition of proper time.

Conclusions

The examples presented show to what extent multimedia representations can be investigated as specific tools for helping students in physics modelling activities and in metacognitive processes about scientific knowledge.

In particular:

- the specific representations we have designed concerning optics show that schematizations through pictures and animations can enable students to follow the process of eliminating the secondary aspects of actual situations; to mentally visualize interpretative elements of experimental situations not directly perceptible; to construct the ideal elements on which a physical model is built;
- the virtual cart collisions inquiring setting is an example of how interactive simulations can be used in addition of real laboratory experiments. Indeed, virtual experiences, due to the interactive aspect, permit to design extremely flexible teaching paths

concerning situations that can vary from relatively simple to highly complex;

- Schematic 2D/3D interactive animations about thought experiments can be explored for guiding students through a reasoning that - with clear drawings, simple languages and without mathematical complications - moves from the postulates of a Modern Physics theory and leads to its counterintuitive ideas.

Moreover, the animations, if well managed by the teachers, can foster discussions about the epistemological implications of theories which imply basic concepts and their relationships with the real world.

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Various Physics

Modelling dynamical equilibrium in emission and absorption of radiation

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Abstract

A very simple experiment often programmed already in primary schools is to observe the temperature rise of a black object exposed to solar radiation and to compare it with the temperature rise of an identical white object exposed in similar conditions.

The physics of this simple experiment is however much richer than one generally realizes at this basic level. For example, it is not common to compare also the rate of cooling of the two objects: one observes, if the measure is done correctly, that the black object cools faster than the white one, as expected from Stefan Boltzmann and Kirchhoff laws [1]. It is also very instructive to measure how the rate of temperature rise slowly decreases in time until a *dynamical equilibrium temperature* is reached: when this happens, the rate of energy absorption is equal to the rate of energy emission and both the equilibrium temperature and the relaxation time depend critically on the type of object and of the experimental conditions.

In the paper we discuss results obtained by high school students during a stage in our university lab and a simple model developed to interpret the data in terms of dynamical equilibrium between absorption and emission of radiation, which shows the complete similarity between the two processes.

The experiment

The experimental setup is shown in figure 1. It consists of two identical metal cans, one painted white and the other black, and of an incandescent high wattage lamp to provide the radiation symmetrically to the two cans. To record the temperatures the students could use either

manual thermometers or online ones, with the readout through an ADC converter and a graphic calculator.

Typical results are shown in figure 2. The lamp was on until the temperature rise of both cans seemed negligible, indicating that the dynamical equilibrium between the energy absorbed from the lamp and the energy released by conduction and radiation



Figure 1

emission was very near. The lamp was then turned off and the

temperatures of the two cans were measured during the cooling process until the room temperature equilibrium was very near.



Figure 2

The curves obtained for both cans show a similarity between the heating and the cooling processes: in the heating process the temperature seems to approach a "dynamical equilibrium temperature", which is clearly larger for the black can, and during the cooling process the temperature seems to approach a "static equilibrium temperature", which should be the same for the two cans and close to the room temperature.

The model

Modelling the evolution of a physical process is a powerful method to understand it, as is well known from educational research [2]; cooling and heating phenomena are particularly suitable [3], because the model helps to organize the spontaneous reasoning which is natural for such familiar processes.

We modeled the approach to equilibrium with an *exponential law*, both for the static and for the dynamical case. During heating, the difference between the "dynamical equilibrium temperature", T_{dyn-eq} , and the temperature T at time t is assumed to decrease exponentially in time with a characteristic relaxation time τ_d :

$$\Delta T = T_{dvn-eq} - T = T_{od} e^{-t/\tau_d} \tag{1}$$

The data suggest T_{dyn-eq} to be clearly larger for the black can than for the white can and to depend upon the power of the radiation source; it is more difficult to visually compare the dynamical relaxation times of the two cans, although it seems smaller for the black can.

During cooling, the difference between the temperature *T* at time *t* and the "static equilibrium temperature", $T_{stat-eq}$, is assumed to decrease exponentially with a characteristic relaxation time τ_s :

$$\Delta T = T - T_{stat-eq} = T_{os} e^{-t/\tau_s}$$
(2)

The data suggest $T_{stat-eq}$ to be roughly the same for the two cans and close to the room temperature.

To determine the parameters of the model a simple "excel" work sheet was used: the temperature differences defined according to equations (1) and (2) for the two processes were plotted on a logarithmic scale as a function of time, using tentative values of the equilibrium temperatures, which were manually varied until a good fit to a decreasing exponential behavior was obtained.

The logarithmic plots are shown in figure 3 for the two cans and the best fit values are collected in table 1.





	$\tau_d \approx \tau_s$	T _{dyn-eq}	T _{stat-eq}
Black can	≈ 120 s	55,5 °C	22,5 °C
White can	≈ 200 s	39,1 °C	21,1 °C

Table 1

The main conclusions are:

- the model describes well both the heating and the cooling processes, showing that the underlying dynamics are the same: the fact that the equilibrium temperature is approached with a decreasing exponential law shows that the energy loss is roughly proportional to the difference between the present temperature and the equilibrium temperature²⁶, both for cooling and for heating;
- the characteristic relaxation times τ_d and τ_s during heating and cooling are very similar, for both cans, showing that the underlying energy loss processes are the same, as expected from Kirchhoff law, that is the absorption and the emission of radiation are mirror processes; in particular the characteristic relaxation times τ_d during heating are independent of the power of the radiation source, contrary to what one would naively expect, since they are close to τ_s ;
- the characteristic relaxation times τ_d and τ_s of the black can are significantly smaller than those of the white can, as expected, since the black can is *more strongly coupled* with the environment;
- the dynamical equilibrium temperature of the black can is larger than that of the white can and both depend upon the power of the radiation source, as expected;
- also the static equilibrium temperature of the black can is larger than that of the white can, contrary to the naïve expectation: this fact suggested further investigation as we will discuss below.

The rate of the temperature variation

The above analysis indicates that the key variable of this kind of process is the rate of the temperature variation, because, according to the model, it should show more clearly the mirror exponential behavior of the heating and cooling processes:

$$\frac{dT}{dt} = -\frac{d(T_{dyn-eq} - T)}{dt} = -\frac{d(T_{od}e^{-t/\tau_d})}{dt} = \frac{T_{od}e^{-t/\tau_d}}{\tau_d} \quad \text{during heating (3)}$$
$$\frac{dT}{dt} = \frac{d(T - T_{stat-eq})}{dt} = \frac{d(T_{os}e^{-t/\tau_s})}{dt} = -\frac{T_{os}e^{-t/\tau_s}}{\tau_s} \quad \text{during cooling (4)}$$

²⁶ For the radiation one would indeed expect a proportionality to T^4 , but, for the small temperature differences involved in the experiment, the linear approximation works well.

In figure 4 we show the plots of the temperature variation rate of the two cans as a function of time, where the "mirror" behavior is directly appreciable.



Equations (3) and (4) show also that the temperature variation rate is a linear function of the temperature with slope $1/\tau$.

$$\frac{dT}{dt} = \frac{T_{od}e^{-t/\tau_d}}{\tau_d} = \frac{T_{dyn-eq} - T}{\tau_d} \quad \text{during heating} \quad (5)$$
$$\frac{dT}{dt} = -\frac{T_{os}e^{-t/\tau_s}}{\tau_s} = \frac{T - T_{stat-eq}}{\tau_s} \quad \text{during cooling} \quad (6)$$

From the plot, shown in figure 5, of the temperature variation rate as a function of temperature, we can thus determine with a simple linear fit all the



parameters of the model, which are collected in table 2.

	$ au_d$	$ au_s$	T _{dyn-eq}	$T_{stat-eq}$
Black can	118 s	115 s	55,3 °C	23,0 °C
White can	172 s	185 s	37,9 °C	22,2 °C

Table 2

The best fit values are in complete agreement with those obtained in the previous analysis and therefore confirm the conclusions presented above.

A home made radiometer

A puzzling result of the above experiment is that the static equilibrium temperature appears to be slightly larger for the black can than the white can. Since similar differences were obtained also when repeating the experiment in different conditions, we concluded that the effect was real and that the black can was more sensitive than the white one to the presence of small amounts of IR radiation present in the lab. We thus prepared a "home made radiometer" using two small black painted metal strips fixed at the two opposite sides of a cube made of insulating material (figure 6). Having a smaller mass, this "radiometer" is more sensitive than the black can to small variations of IR radiation and also it is more sensitive to the direction of the IR radiation, which is an important feature to disentangle energy absorption by radiation and by conduction. In the figure the radiometer was put on a table in the garden, with one side facing the house wall and the other facing the garden, just before sunrise: the two thermometers indicate a small but significant difference between the two temperatures, indicating that more IR radiation was coming from the wall. As the sunrise advanced, the temperatures slowly changed and the difference was completely reversed much before direct sun light hit the outer thermometer!

Conclusions

Figure 6

This simple experiment, which can be performed with basic instrumentation, is very instructive to show the unique features of the energy exchange by radiation and the importance of a good mathematical model to correctly interpret the dynamics of the coupling with the environment which allows reaching the equilibrium conditions.



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A Proposal for the Use of Structural Models in Physics Teaching: the Case of Friction

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Abstract

Formal models are insufficient for learning at school age and unsatisfactory for the student's need to understand. We believe it important to propose *structural models* which can favor reasoning, interpretations and predictions, and are intellectually fruitful because they stimulate inquiry into entities and processes supposed to exist in material systems. We developed a teaching learning sequence on friction grounded on these ideas and based on a didactical reconstruction of the physics content, which has been tested in preservice teacher education.

1. Teaching friction: how it is usually handled and students' difficulties

In secondary education, friction is generally presented as a marginal phenomenon and in a schematic way. Thus all the complexity and variety of friction phenomenology, which is object of numerous studies, go unrevealed.

Apart from a brief mention of the effect of surfaces "roughness", the solid bodies at contact are nearly always considered rigid bodies and represented by regular rectangles moving on planes indicated by segments. The rigid body schematization hinders any attempt to create an image of the mechanisms which can be the basis for a causal explanation of friction. It is just the image that many students seem to need to understand physical situations, as previous research has proved (Brown 1992, Ogborn 1993, Besson & Viennot 2004). This is a typical situation in which schematization is sufficient to *calculate*, on the basis of simplified laws, physical quantities requested in problems, but it is unable to make students *understand* the physical situation, for which deformations of solids are essential (Besson 2004).

Physics education research has shown some specific difficulties and conceptions on friction (Caldas-Saltiel 1995, Besson 1996), e.g. a tendency to refuse the possible motive role of friction, to identify normal force with weight, to consider only the friction force acting on the object in motion or stimulated to move, etc.

2. Reconstructing the physics content within a teaching perspective

A teaching proposal on a scientific subject demands reconstructing the topic to transform scientific knowledge in teachable knowledge (Chevallard 2005, Kattman et al 1997), taking into account the cognitive and didactic problems.

When consulting some modern treatises of tribology (Quinn 1991, Persson 1998, Bhushan 2002), one realizes how complex the topic is and how vast the problems, applications and theories are. Amongst all this material a choice has to be made of content-matter, models and examples which are suitable for secondary school.

Moreover, some recent developments are unknown to most teachers and many experimental and theoretic results, not even very recent ones, *contrast* with the laws normally proposed in physics handbooks. A few examples may illustrate this problem.

For sliding friction, handbooks generally present the classic laws, attributed to Amontons and Coulomb, according to which the friction force F is proportional to the normal force W, independent of the contact area A and, in the dynamic case, independent of the speed. However, things are not so simple.

For some materials relations have been found of the type $F \propto W^n$, with n < 1 (e.g. textile fibers, polymers, numerous rocks). In many cases, the relation between friction force and load is complicated and cannot be expressed by a mathematical formula.

Moreover, there are various *sticky materials*, which present friction even without a load or with a "negative" load, such as plasticine, putty, resin... Similar behavior has been observed in *nanotribology* experiments, founding relations like $F = \mu W + kA$, with an adhesive term kA, proportional to the area.

The independence of the kinetic friction force from the velocity is not generally valid.

The mechanisms at the origin of friction have been the object of doubts and controversies.

According to Amontons and Coulomb, the origin of sliding friction lies mainly in the interlocking and deforming of the surface asperities, whilst Desaguliers (1734) and Vince (1785) emphasize the importance of adhesion and Tomlinson (1929) the role of phononic energy dissipation. Today different mechanisms are considered, the relevance of which varies according to situations (adhesion, deformation and plowing of surfaces, elastic hysteresis, breaking of asperities and wear).

3. A teaching learning sequence on friction

To overcome the common difficulties concerning this topic and to help acquire the elements of an explicative model which allows constructing an image of the mechanisms producing friction, we have elaborated a Teaching Learning Sequence on friction between solids, based on the didactic choices summarized below:

- ✓ Present friction as an almost omnipresent set of phenomena that are crucial for most everyday activities.
- ✓ Start by giving examples where friction is presented as a positive "resource", rather than merely as an "obstacle" or "loss".

- ✓ Emphasize how friction is necessary to establish equilibrium after stress or motion.
- ✓ Refute the idea according to which friction always has a resistive effect, generating a force which opposes motion and acts only on the object in motion or stimulated to move.
- ✓ Avoid too much focusing on situations with horizontal friction forces which can favor identification between normal force and weight.

As for the use of models, we believe that formal models, in terms of functional relations expressed by formulas, are insufficient for learning at school age and unsatisfactory for the student's need to understand. We propose using appropriate *structural models* which allow, although to a limited extent, reasoning, interpretations and predictions. The incompleteness of the model is discussed at the very beginning, together with the degree to which it fits physical reality, i.e. its similarity to material elements and mechanisms *which really do exist*. These models have an *explanatory function* and are cognitively fertile, because they stimulate research on the entities and processes which are presumed to exist within the material system.

The sequence is organized into six parts, briefly described below.

3.1 Introductory observations and experiments

Simple qualitative experiments illustrate the different typologies of friction, in situations in which friction is considered to be a disturbance or a useful phenomenon. First, experiments are based on the question "What would happen if there were no friction?" in daily activities such as picking up a bottle, walking, weighing with a spring scale, pouring liquid into a container, carrying glasses on a tray etc.

Observation of damped oscillations of liquids, springs and metal wires, introduces internal friction while other experiments emphasize the role of adhesion and the particular behavior of "sticky" materials.

3.2 Vertical friction: definition of descriptive quantities and first qualitative relations

To keep the student from identifying normal force with weight, an experiment is proposed in which a vertical friction force is present and normal force is not related to weight: small wooden boards are pressed against a wall first by a finger, then by a force probe, so as to allow measurements.

The teacher shows other ways of producing a normal force (a magnet, an accelerated paddle).

A first theoretic framework is provided, introducing some quantities essential to a scientific and not merely empirical study (normal force or load, friction force, friction coefficient, contact area). Students are encouraged to propose schematic models of the surfaces in contact, which could help account for the observed behavior.

3.3 Phenomenological laws on static and kinetic friction

A more systematic experiment is carried out, in a situation of horizontal motion, by using a computer Data Acquisition System: students analyze the variation in time of the friction force and its dependence on the load and on the contact area.

3.4 Static friction and rolling

The knowledge acquired is applied to the case of rolling, which causes difficulties to many students (Rimoldini-Singh 2005). A logical progression is proposed, starting from an analysis of the overturning of a cube and of an octagonal prism, and leading to the physical mechanism of the rolling of a cylinder, considered as a limit case of a prism. Emphasis is placed on the role and direction of static friction force in different ways of rolling (cylinder pulled by a force applied to the axis or rolling due to a torque), by using specific experiments.

3.5 Structural models: topography of surfaces and mechanisms producing friction

The classic friction laws are discussed as phenomenological laws, requiring explanations on the underlying phenomena. It is emphasized that in many cases different empirical relations are found.

The surfaces topography and the distinction between apparent and real area are presented, by means of figures and drawings. Some mechanisms producing friction are presented in a simplified and intuitive way: adhesion between the surfaces asperities; deformation, tracking or scratching of surfaces; impact and interlocking among asperities; wear; deformation and abrasion due to particles trapped between the surfaces. Some historical explanatory models of sliding friction phenomena are presented together with some more recent ones.

3.6 Friction phenomena from the point of view of energy

Qualitative experiments are discussed, emphasizing the energy transfers towards *internal* parts of systems: damped oscillations of metal blades and of cylinders containing lead shot, inelastic collisions of a cart equipped with many oscillators...

The process can be modeled as a double passage of energy, first from macro to mesoscopic level, then from mesoscopic to microscopic (Besson 2005).

The damped oscillations of metal blades represent a bridging analogy for a first explicative model of energy exchanges in sliding: the asperities of the contact surfaces are depicted as mesoscopic blades-springs, the motion causes a deformation in them, thus transferring macroscopic energy in elastic mesoscopic energy. Then the asperities-springs separate and oscillate, with a rapid damping, thus transforming the mesoscopic energy into microscopic energy. This model is immediately criticized because it does not account for various aspects such as approximate independence from area, while the usefulness of partial models, explaining only particular aspects of the phenomenology is stressed. Another model is then proposed with more widespread asperities, which can be deformed and crushed under the load, as a step through the adhesive junctions' model of Bowden-Tabor (1950).

4. Evaluation of the sequence

The sequence was first tested with two groups of student teachers (N_1 =24, N_2 =22), then six of them proposed it in three high school classes in which they carried out their training, and later it was proposed to expert teachers, which adapted and used it in their classes. To facilitate the reproducibility of the sequence in a real school context, we have designed an *open source structure*, in which there is a *core* of contents, conceptual correlations and methodological choices with a *cloud* of elements that can be re-designed by teachers who can create new versions of the sequence. The teachers' work provides a feedback useful not only to test the effectiveness of the proposal or to identify its points of weakness, but also to enrich it with new elements.

The evaluation was carried out by means of a pre-test, two post-tests, work-sheets and reports written by the students, reports and comments provided by teachers and observers. Significant positive results were found. We give here only some examples.

4.1 Friction force as motive force and direction of static friction force

The motive role of friction force, with the correct indication of its direction, is understood only by a minority of students in the pre-test (16%, a block placed on a cart), and by 100%, 86% and 72% in the post-test, respectively, in three different cases: a block pulled over a mat, a dish lying on an accelerated cart (fig. 1a), and an object on a rotating carousel (fig. 1c).



Figure 1. Examples of situations proposed to students in the final test.

a) A wooden block is pushed against a wall by a horizontal force. b) A cart with a dish placed on it is put in motion with a small acceleration, then moved at uniform motion and finally slowed down. c) An object is placed on and remains at rest with respect to a carousel rotating at constant speed

4.2 The phenomenological and approximate nature of the classical laws of friction

In the answers to the post-test, many students underline that the independence of the frictional force from the contact area and the proportionality between frictional force and normal force are only approximate and not always true. Some quotations: "the proportionality between frictional force and normal force is not fully respected", "for sticky materials this proportionality is not valid", "the kinetic friction force does not depend on velocity, but sometimes it does", "the usual empirical law is not always valid".

4.3 Use and effectiveness of a structural model

The consideration of a structural model, nearly absent at the beginning, increases progressively. Many students (86%) used, in different situations, a mesoscopic structural model (represented by drawings and verbal descriptions involving asperity interactions) to support their answers and explanations. In the situation of the dish on a cart (fig. 1b), *none* of the students (8) who indicated a wrong direction of the friction force during the acceleration of the cart had done drawings regarding the model; on the contrary, among those who did such drawings (30) *all* answered correctly for the phase of acceleration and almost all (78%) for the three phases of acceleration, uniform motion and deceleration. In this case, the model is not merely a figurative representation, but it takes on an operative explicative function, even if in a very simplified form, because the asperities are depicted deformed in a different way in the situations of acceleration, deceleration and uniform motion.

5. Conclusions and implications

This research has touched many different aspects involved in the design and implementation of a teaching sequence, confirming the importance of a critical reflection on the content matter in view of its reconstruction for teaching purposes.

We aimed at avoiding premature schematizations, at presenting phenomena in a way which is faithful to reality and to the current scientific knowledge, and at accustoming students to reason qualitatively on complex real situations.

The testing of the sequence with prospective teachers has provided encouraging results, from the point of view of overcoming some typical difficulties with the topic and of activating new, richer reasoning. Positive elements emerged from the comments of teachers and students, in terms of motivation, interest, challenge and feasibility.

As regards the use of structural explicative models, which we consider important for understanding physical situations not merely with manipulations of formulas, the reception has been positive. The characteristics of the proposed models have been the basis for articulate qualitative explanations. The reasoning produced by the students, although incomplete, rises to a much more refined level than the simple repetition of fixed and abstract rules based on idealized objects.

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Rationale for and implementation of an empirical-mathematical modelling approach in upper secondary physics in Norway

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Abstract

We present a rationale and a framework for empirical-mathematical modelling in upper secondary physics, and report on a project focused on empiricalmathematical modelling in Norwegian physics classrooms. The project particularly aims to give students experience with the many forms of representations applied in models of physical reality.

Introduction

A contemporary education in science is expected to serve two broad purposes: To provide society with a *competent workforce* and with *scientifically literate citizens*. In this paper we focus on how *upper secondary school physics* may contribute to developing students' competencies and literacy in the field of physical science, and we suggest an approach – *empirical-mathematical modelling* – that we believe can meet some challenges facing physics education and thereby contribute to serving these two overall purposes. By empirical-mathematical modelling, we mean an approach where 1) students work with open-ended experiments and gather data which they use to construct mathematical models of the phenomena under study, and 2) teaching has a general emphasis on physics as a collection of "models of natural phenomena", and "doing physics" means working with models in a wide sense of the term.

Our choice to look into empirical-mathematical modelling was motivated by a previous research project (Angell, Guttersrud, Henriksen, & Isnes, 2004) and six more specific challenges facing physics education, all of them related to the two overall purposes of science education. Research on students' understanding and learning indicates that physics education needs to focus on:

1. the use of, and interchange between, *multiple representations* of physical phenomena

- 2. the *role and purpose of experiment* in physical science
- 3. the relationship between mathematics and physics
- 4. *the nature of science*
- 5. fruitful *learning strategies* for gaining understanding in physics
- 6. skills in *scientific reasoning*

These are by no means the only challenges facing a contemporary physics education; nor can we expect to meet all of them fully through a single approach. However, these are important challenges which have informed our work and which we believe that we can to some extent meet by a stronger focus on empirical-mathematical modelling in upper secondary school physics.

In this paper, we draw on science education research as well as experiences from a research and development project in Norwegian upper secondary school physics in view of the following purpose:

to examine the rationales for, and implementation of, an upper secondary physics education developed around the central concept of empirical-mathematical modelling

In the science education literature, there is a vast number of publications concerning "models" and "modelling", but the terms are used in a wide range of meanings. For instance, much research has focused on analogical models as a teaching tool (such as the water analogy for electric circuits). Another research strand is the use of computer modelling as a means of offering students a deeper understanding of complex phenomena (Sins, Savelbergh, & van Joolingen, 2005).

There is much less research focusing on the empirical and mathematical aspects of modelling. Some projects, however, have focused on mathematical modelling. For example, Oke and Jones (1982a; 1982b) provided two examples of mathematical modelling and argued that it should form an important part of undergraduate courses in science and technology. Indeed, one might argue, mathematical modelling of the physical world should be the central theme of physics instruction (Hestenes, 1987).

Empirical-mathematical modelling in Project PHYS 21

Overview of the PHYS 21 project

The research and development project termed "Physics education for the 21st century" (PHYS 21), emphasising empirical-mathematical modelling, was developed as a response to the six challenges listed above. 10 schools, almost 20 physics teachers and almost 300 students participated in the project, trying out new material and activities involving empirical-mathematical modelling along with a focus on scientific reasoning. The project started with development of material and teacher workshops (2003-2004) and went on to a "pilot year" (2004-2005) and a full implementation year (2005-2006). Workshops and meetings for participating teachers took place during the whole period. A student booklet and a teacher booklet introduced project participants to the view of physics applied in the project, aspects of scientific method and scientific reasoning, examples of scientific models and the modelling process, and suggestions for student modelling activities.

Researchers visited all project schools during modelling activities, made notes, took video clips or sound recordings, and interviewed some of the teachers (note: not all the mentioned methods were employed in every school). During the pilot year, focus group interviews were held with students. A written test was developed to test students' modelling skills, and a questionnaire was designed to investigate students' learning strategies, views on the nature of science, and experiences from the physics classroom. Results from the test and questionnaire are reported in Guttersrud (2006).

Conceptualizing empirical-mathematical modelling in physics

Our understanding of modelling in project PHYS21 is strongly influenced by Jens Dolin's (2002) characterization of physics in terms of multiple forms of representation (experiments, graphs, pictures and diagrams, verbal descriptions, formulas). Part of the challenge of learning physics is to get an overview of all these different representations simultaneously and to manage the transformation between them (Dolin, 2002). In the project PHYS21, efforts were made to make the transitions between the various forms of representation in physics explicit to students.

As a part of our thinking relating to this project, we have developed a conceptualization of physics as a set of models of natural phenomena, each model encompassing a range of different forms of representation (figure 1). This description of models in physics guided our research and development in the project.





Interchange between and simultaneous application of the representations constituting the scientific model

As indicated in figure 1, the starting point for a scientific model is a phenomenon observed in nature. The phenomenon may in physics be represented in a number of different ways (represented by the boxes in the figure): experiments, graphs, pictures and diagrams, verbal/conceptual descriptions, and mathematical equations. As an example, consider the phenomenon "free fall". Dropping an object is a simple experimental representation of this phenomenon, and a sketch of a falling object is a pictorial representation. Defining change in velocity with time as acceleration takes conceptual representations into account. The formula $v = v_o + at$, which in this case reduces to v = gt, is one of the mathematical representations, and the velocity may be represented graphically as a function of time.

Learning to master the model involves both learning to simultaneously apply and interchange between the various representations, and to refine one's mastery of each representation, for instance by acquiring the appropriate physical concepts and terminology and the mathematical "tools" such as derivation and integration.

Modelling activities in PHYS21 classrooms

Essential to our project is giving students opportunities to develop mathematical models of concrete phenomena, preferably in contexts where they don't know the "correct answer" in advance. The elongation of jelly babies (elastic jelly sweets) is an example of a modelling task in the project (figure 2). Students are expected to draw graphs and construct and interpret mathematical expressions to describe the phenomenon.

Fig 2:Experimental and graphical representation of the force as a function of elongation of jellybabies





In most cases, students found a linear relationship, at least for one part of the measurements. The graph passes through the origin, and the linear part can be expressed as f(x) = ax + b where b = 0 which results in F = kx (Hooke's law). Furthermore, the students could realise that the linear model has a limited domain of validity. For large forces, the elastic properties of the jelly change, and the linear model does not fit anymore. Jelly babies with different colours give different slopes of the graph, which may be interpreted as different elastic properties depending of the colouring agent. Also, when a jelly baby is stretched to its maximum without breaking off, the slope will not be the same if a new elongation is carried out. This has to do with the elastic properties of the material, which changes when stretched close to the breaking point. This activity involves a lot of opportunities for challenging students' understanding and concepts in physics. Moreover, the core here is to manage the different forms of representations (experiment, graphs, physical concepts and mathematics) and be able to make a mathematical model within acceptable boundaries.

As can be seen from the example, students in the project were encouraged to use and interchange between multiple representations of physical phenomena; the relationship between mathematics and physics was made apparent for them, and there was a focus on scientific reasoning related to experimental results, particularly by proposing hypotheses and testing them out experimentally.

Some experiences from project PHYS21

- Despite mild, but clear directions from the project management, the teaching strategies used in different PHYS21 classrooms varied widely.
- Teachers appreciated the chance to give an in-depth treatment of fundamental concepts based on the empirical-mathematical modelling approach
- Questionnaire results indicate that teaching approaches were more experiment- and model-based in PHYS 21 classrooms than i regular classrooms, and that students had reflected on this fact
- Students are unaccustomed to aspects of empirical-mathematical modelling such as choosing the appropriate axes for plotting independent and dependent variables.
- An interesting observation was how students used the trend line and regression tool on their calculators. For example when measuring the elongation of jelly babies, several students found complex equations including a lot of factors and corresponding constants. However, none of these constants could be said to have any physical interpretation. It seemed that they just used the tool given on their calculators without thinking of what the result had to do with the actual experiment they where conducting.

Summary and conclusion

In this paper, we have argued that empirical-mathematical modelling should be given a more prominent role in physics education based on the overall purposes of science education and as a response to six more specific challenges facing physics education. There are also other examples of recent approaches which, to various degrees, incorporate (mathematical) modelling and use of ICT, emphasise understanding of basic concepts and the relationship between experiment, reasoning and theory, etc (Carlone, 2003; Feldman & Kropf, 1999; Hestenes, 1987, 1996; Teodoro, 2002; Wells, Hestenes, & Swackhamer, 1995)

Although we have identified some issues that need further development in order for our modelling approach to work optimally in the classroom, we do think, based on our experiences and the arguments for empirical-mathematical modelling presented throughout this paper, that there is reason to develop this strategy further. Among the many demands expected to be made on future citizens and professionals are adaptability, ICT skills, flexibility and creativity. We will argue that empirical-mathematical modelling is relevant to fostering such skills. Empirical-mathematical modelling at its best demonstrates how "doing physics" can be a highly creative activity, and may thereby possibly contribute to improved recruitment.

References

Adapting Gowin's V Diagram to Computational Modelling and Simulation applied to Physics Education

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Abstract

Several research papers in physics education suggest that computational activities in modelling and simulation are potentially useful to facilitate meaningful learning in physics, provided that students engage themselves in these activities and critically think about them. Sometimes, excited with the possibilities offered by technological resources, we imagine that some representations "speak by themselves" in such a way that students' comprehension of physical phenomena will occur just by seeing them. However, to know how to use an instructional tool is at least as important as having it. In the case of computational modelling and simulation, for instance, it is not enough just to use them in instruction, it is necessary to make students think about what they are doing, about the physics involved in the models and simulations that they are dealing with. Thus, we decided to build an heuristic tool to help students in the task of creating and analyzing computational models useful to investigate the telling questions proposed regarding some physical phenomenon of Gowin's V diagram to computational Modelling and simulation.

AVM diagram

Among the many ways of using the computer in the teaching of science in general, and physics in particular, the computational activities of simulation and modelling stand out for potentially allowing students a better understanding of scientific models expliciting relationships among variables, the visualization of highly abstract elements, and their interaction with the content to be learned, among other things. These activities, as we see them, are distinguished from one another; basically, because of the access the student has to the mathematical or iconic model underlying its implementation. In a computational simulation representing a physics model, the student may add initial values to the variables, change parameters and, in a limited way, modify the relationships among the variables; however, he/she does not have autonomy to change the heart of the simulation (defined by a pre-established mathematical model), that is, to access the most basic constitutional elements. Student's interaction with the simulation has an eminently exploratory character. Computational modelling can also be thought in exploratory terms; in this case, the student receives a computational model ready and must explore it, but with the difference of having access to its basic features, even though, in some activities, he/she may not be asked to alter the basic structure of the model.

The exploratory activities, in general, are characterized by observation, analysis and interaction of the subject with previously built models so as to allow the perception and the understanding of possible existing relationships between mathematics, which underlies the model, and the physics phenomenon in question. In this kind of activity, the student is motivated to interact with the computational model, by answering questions presented as directed questions and "challenges". This interaction occurs through changes in the initial values and parameters of the model, using resources such as "scrolling bars" and "buttons" to facilitate the modifications. In the case of the exploratory activity of computational modelling, the student has access to the basic structure of the implemented model, being able to change it if he/she desires to do so.

Another possible way of working with computational modelling applied to teaching is the so-called expressive mode¹. The activities developed in this mode can be characterized by the developing process of the model from its mathematical structure to the analysis of the results it generates.² In this kind of activity, questions aimed at the elaboration of models from certain phenomena of interest, about which qualitative as well as quantitative information on the system may be given, are presented. The student can interact completely with his/her model, redesigning it as many times as it seems necessary to validate the computational model and the production of results that may seem satisfactory to him/her.

¹ Many times called "creation mode".

 $^{^2}$ In this category there are different forms of implementation of the computational model, for instance, inserting mathematical equations and/or building iconic diagrams in appropriate software, or using some programming language.

Based in the great success obtained through the usage of the V diagram, also known as Gowin's V (Gowin, 1981; Moreira & Buchweitz, 1993), in the analysis of the process of knowledge generation, and in order to extract knowledge documented in research papers, books, essays, etc., we decided to propose an Adaptation of Gowin's V to Computational **Modelling** and Simulation (the AVM diagram), as presented in Araujo (2005). The V form of the diagram, originally proposed by Gowin, is not something fundamental. Other forms could be chosen, but we adopted, for the AVM diagram, the V form because it shows the interaction between the two indispensable domains to the development of a computational model guided to the teaching-learning process of physics: the theoretical domain, related to the conception of the computational model; and the methodological domain, associated to the implementation and/or exploration of this model.

In the center of the AVM diagram, there is the phenomenon of interest, which we desire to approach and the focus-questions that direct the analysis/design of the computational model. In the basis of the diagram, there are the problem-situations, which are descriptions of the situation/event under investigation to answer the focus-questions that contextualize the phenomenon of interest.

The left and right side of the AVM diagram can be visualized in detail in figure 1. The left side of the diagram concentrates on the theoretical aspects of the planning/analysis of the computational model. This side shows the *philosophy*, that is, the systems of beliefs underlying the problem-situation modelling process; the *theories*, *principles*, *theorems* and *laws* that guide the development of the model; the *idealizations* and *approximations* assumed, which determine the context of validity of the model; the internal *entities* of the system being modeled and the external agents that act upon it; the signs by which they are represented; the *variables* and *parameters* used to represent states and properties of the entities of the model; the mathematical or propositional *relationships* (a technical statement such as "the bigger this.. the smaller that"); the *known results*, used for an initial validity of the model, which can be inferred from the theories, principles, theorems and laws assumed for the designing of the scientific model that we want to represent in the computer and which will also depend on the previous knowledge the designer has about the system represented. At last, we have the *predictions*, which are no less than initial attempts to answer the focus-questions before carrying out the model.

On the right side of the AVM diagram, corresponding to the methodological domain, there are: the *records*, that is, the data collected to try to answer the focus-questions; the *interactive elements*, related with the possibilities of altering parameters and variables during the execution time of the computational model; the *representations*, given by the model (graphics, table, etc.) and pertinent to the search for answers, obtained from the transformation of records; and the *modelling categorization*, according to the following classification concerning:

- a) mode (*expressive*: when a model is built by the subject; or *exploratory*: when the subject just explores it);
- b) kind (*qualitative*: linked to the modelling of linguistic constructions and textual productions; *semi-qualitative*: linked to the usage of causal diagrams, not involving numerical relationships; *quantitative*: bonded to mathematical models, involving numerical values and relationships as inequality and equations);
- c) implementation: in the expressive mode, a description of the way in which the model was implemented in the computer (through the use of metaphors, programming language, insertion of equations similar to manuscript form, etc.) and the tool used (*PowerSim, Fortran, Modellus*, etc.) In the exploratory mode, an indication of whether it is an autonomous simulation, or it needs to be executed in some program must be expressed. The computational tool used to build the simulation also must be indicated whenever possible.

Still on the right side of the V, we have the *validation of the model* step, in which we compare the known results with the ones generated by the model. In case there is a disagreement between them, the model is considered unsatisfactory and must be modified until it comes to reproduce the known results. In this stage, the model is said to be validated. Then, we come to obtain the model assertions, that is, the answer (s) to the focus-question(s) that are reasonable interpretations of the records and representations supplied by the model, also allowing the evaluation of the predictions. At last, we have the *possible generalizations and expansions* of the model, which are the generalizations about the applicability of the structure of the model and how to expand it in a way to include variables and relationships not considered initially (change in idealizations and principles), broadening its context of validity.

It is important to emphasize that there is a permanent interaction between both sides of the AVM diagram in a way that everything that is done in the methodological side is guided by the components of the conceptual side in an attempt to develop/analyze the model and answer the focus-questions. This interaction mimetizes the recursivity intrinsic to the modelling process. We propose four applications of the AVM

diagram to the teaching of computational modelling and to the exploration of computational simulations to the learning of specific contents.

- Guided exploratory mode: in the AVM diagram, the phenomenon of interest, the focus-questions and the problem-situation are defined by the teacher and a computational simulation is presented. The reflexive elaboration of the V will serve as a guide to the exploration of the model so as to answer the focus-questions. Activities built this way may avoid that students distract themselves with details and end up not capturing essential aspects of the model focused by the teacher, especially when in too elaborate and "realistic" simulations.
- 2) Open exploratory mode: a computational simulation is presented and it is asked that, through the AVM diagram, the student explores the model in a reflexive manner, paying special attention to the formulation of the focus-questions. This mode may be especially useful for designing educational materials from the simulations created by others, which is interesting to the teacher, who can come to use the materials available in the web, for example, as well as to the students.
- 3) Expressive guided mode: in this case, the phenomenon of interest, the focus-questions and the problem-situation are previously supplied by the teacher, while the student elaborates the rest of the V and designs the corresponding computational model. This mode can be used when we desire the students to build a computational model about a specific content, taking in consideration focus-aspects defined by the teacher.
- 4) Open expressive mode: these are proposed activities in which the student must design a computational model from the reflexive elaboration of the AVM diagram, defining him/herself the focus-questions and the problem-situations which will guide his/her work. This way of using the AVM diagram may also guide the teacher in the building of his own models.

During the process of creation of the AVM diagram as an heuristic tool for the computational modelling and simulation applied to the teaching of physics, we considered the five non-hierarchical stages defined by Halloun (Halloun, 1996), the six stages defined by Santos & Ogborn (1992), the strategy for building models presented by Ferracioli & Camiletti (2002), the considerations on the modes and kinds of computational modelling activities done by Santos & Ogborn (1994) and also elements of the P.O.E. (Predict Observe Explain) methodology (Tao & Gunstone, 1999). These elements appear "diluted" in many fields of the AVM diagram and their stages, in the dialectic process of its development.

In the teaching activities of the exploratory mode, we motivate the student to question him/herself about the existing relationships among the many variables involved, driving him/her to constantly question about the effects of his/her actions upon the results generated by the model. This questioning can usually be described as: If I alter "this" what happens to "that"? This causal underlying reasoning acts as backround to the promotion of interactivity. In the expressive mode teaching activities, the AVM diagram was conceived to serve as an heuristic tool to the development of computational models applied to teaching.

Example

In figure 2, an example of AVM diagram is given. It is just an example, not an exemplar. It was made by an introductory college physics student, in the expressive guided mode, has inadequacies in the scope of physics, for example, the assumption that the electric current in the circuit increases during the charging process of the capacitor. This AVM diagram was chosen as example because it illustrates well the difference between known results (which we assume as true in the designing/analysis of the computational model), and the predictions (answer attempts to the focus-questions). In an AVM diagram developed by someone who knows the content, and, therefore, who previously knows the answers to the focus-questions, the results obtained and the predictions may superimpose each other.

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Figure 1 - Adaptation of the epistemological V to computational Modelling

CONCEPTUAL DOMAIN

Beliefs

World views; general and comprehensive deep beliefs about the nature of knowledge underlying the development of the computational model.

Theory(ies), principle(s), theorem(s) and law(s) Organized set of principle(s) and concepts linked to the phenomenon of interest and to the objects and/or events of study that guide the construction of the computational model. Statements of relationships among concepts that orient the elaboration of the model explaining how one can expect the events or objects in study to present or behave themselves.

Idealizations/approximations (context of validity) Simplifications assumed in the elaboration of the physics model, seen as a structural and non specular analogous of the phenomenon it represents.

Entities/ signs

Objects composing the system to be modeled and objects which characterize the external agents that interact with the system, as well as their respective symbolic representations.

Concepts: Variables/Parameters

Properties and state descriptors related to the entities which will constitute the computational model.

Relationships

Mathematical and/or propositional relationships involving the variables and parameters of the physics model.

Known results

Some known results which will allow for the initial validation of the computational model.

Predictions

Answer attempts to the focus-questions before the construction or exploration of the computational model.

Phenomenon of interest Definition of the phenomenon to be approached.

Focus-question(s) To be answered through the building/analysis of the computational model.



Problem-situation Description of the situation/event related to the focusquestions which contextualizes the phenomenon of interest.

METHODOLOGICAL DOMAIN

Possible generalizations and expansions of the model

Generalizations on the applicability of the structure of the mathematical model and expansion of the physics models as to include variables and relations not defined previously (changes in idealizations and principles), broadening its context of validity.

Claims of the model

Statements that answer the focus-question(s) and which are reasonable interpretations of the records and representations supplied by the model; evaluation of the predictions.

Model validation

Comparisons between the known results with the ones generated by the computational model, observing whether the relations already established between variables are being verified.

Modelling categorization

a) concerning the mode: exploratory or expressive (model construction);

b) concerning the kind: qualitative (linguistic), semiqualitative (casual relations, non-mathematical), quantitative (mathematical);

c) concerning the form of implementation/interaction: usage of metaphors, manuscript equations, equations defined in programming language, etc. The computational tool used must be indicated whenever possible.

Representations

Graphs, animations, tables and other ways of transforming registers done in the computational model.

Interactive elements

Elements (sliding buttons, rolling bars, etc.) which compose the computational model and are associated to variables and/or parameters, whose manipulation helps to answer the focus-question(s).

Records

Which observations are made (in the computational model) to try to answer the focus-questions (data involved).

Figure 2 - AVM diagram for building a RC circuit model from the point of view of a beginner student (notice the errors in the predictions)

CONCEPTUAL DOMAIN

Beliefs

Models which reproduce the dynamic behavior of an electric circuit can be designed. Theory(ies), principle(s), theorem(s) and law(s) The principle of conservation of energy: Kirchhof's Network Laws; Ohm's Law. Idealizations/approximations (context of validity) The conducting devices are connected by wires of negligible resistance; The source has no considerable internal resistance: There are no "losses" of the capacitor's stored charge to the media: Electrical current continuity. Entities

Wires; Capacitor; Source of direct voltage; Ohmic resistor

Signs

Electric current = i: electric charge = q: electric tension in the capacitor = V_c , in the resistor = VR, in the source = V: Electric resistance = R: Capacitance = C: time = t.

Variables	Parameters
t (s)	V (V)
i (A)	R (ohms)
q (mc)	C (F)
$V_{c}(V)$	
$V_{R}(V)$	

Relationships $V = V_R + V_C$; $V_R = R.i$; $V_c = q/C$; i = dq/dtKnown results For $t \rightarrow \infty$ and $V \neq 0$, i=0 The graph q x t, has the form of an exponential Predictions

1) V does not influence, and the bigger the resistance, the longer the charge/discharge time: 2)Increasing R, it takes longer time to charge; increasing V. less time: 3) The current decreases in the discharge and increases in the charging process.

Phenomenon of interest Electromagnetic magnitudes' variances in resistive and capacitive electrical circuits.

Focus-question(s) 1) What is the role of R and V in the charge/discharge time of the capacitor? 2) What is the behavior of g(t) if we vary R or V during the charge/ discharge time of the capacitor? 3) How does the current vary in the charge/discharge process of the capacitor?

METHODOLOGICAL DOMAIN

Possible generalizations and expansions of the model

The model could be expanded so as to consider the resistance of the wires and of the source. We could express C as a function of the area and model the case of a capacitor of movable plates. The model as it is, in the discharge process exhibits a dynamic behavior similar to the radioactive decay one.

Assertions of the model

1)The higher R or V in the circuit, the greater will be the time needed to charge/discharge the capacitor: 2) increasing (reducing) R the variation rate of the charge with the time, that is, current increases (decreases) as well as the value of the maximum charge which can be stored in the capacitor;

3) In the charge process, as in the discharge one, the current starts at a maximum value (positive or negative, respectively) and, as time goes by, it tends to zero.

Model validation

The known results are achieved with the model. Modelling categorization

a) concerning the mode: expressive b) concerning the kind: quantitative; c) concerning the form of implementation/interaction: manuscript equations (Modellus).

Representations Graphs: q x t; i x t **Interactive elements** Scrolling bars: V: R: Initial values input: q(s). Records i(t); q(t)

Problem-situation The analysis of the dynamic behavior of a RC circuit during the charging/discharging process of the capacitor.

Interaction

Pedagogical Aspects of Teaching Modeling by Means of Doppler Effect; Situations Using parallel Physical and Mathematical Models

Max Bazovsky

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Abstract

The Doppler effect is special pedagogically because it can relatively easily develop modeling competency as an interdisciplinary skill, and because the Doppler effect is extremely simple to state and to model. Doppler modeling starts with two basic types: (a) physical models showing the physics of the process(es) involved, and (b) mathematical models that "live" in abstract space-time graphs. Both of these basic types involve using prior knowledge to connect various skills together from different student "mental boxes" (verbal, pictures, some simple rules or properties of gases, and liquids and solids, diagrams, elementary geometry of triangles and parallel lines, and working with linear graphs). These skills are further reviewed and developed during the Doppler modeling lessons, as is the skill of changing representations, or of translating models from one domain to another, e.g., physical models into first graphic models and then math models – and vice versa. Both the basic types can be creatively manipulated for different contexts. The mathematical models "live" in the abstract space of simple two dimensional space-time graphs. The modeling exercises and examples are a neat way to awaken, motivate and develop student skills and interests. The modeling process proceeds from the simple stationary case to the full Doppler scenario case in many different contexts. When the students see how the models change from context to context, how they are evaluated, and where their limits are, they develop modeling competences, which are transferable to other disciplines, and, they "get the big picture". As an added attraction, we should mention that the modeling development was developed/designed to be consistent with Bloom's taxonomy of the cognitive domain, and was executed by an author who spend most of his career modeling complex systems, with over twenty publications just on fairly specific models in advanced design.

Developing Modeling Competency In General It is hoped the approach to the modeling process and models described herein will become a major example for effectively and concurrently teaching Doppler effect models and modeling in general, concurrently in order to develop the very important and desirable interdisciplinary modeling competency in students, as mandated by the Danish Parliament in 1999 for better education (as described and discussed in [1]). When teaching the beginning of modeling to students in middle and early high school it is important to play with the models so that they get familiarity with their advantages and limitations. To do this it is important to show that the models taught/used are not static things "just to be used without question", by "turning the crank" to churn out numbers, curves and/or tables. Instead, models are to be examined by the student herself, with the magnifying glass of her own mind (minds-on, for modeling). She must not only hear and see, say and write, but most importantly DO (Dale's Cone of Experience, as quoted in [2]). This can occur with sustained/guided play. It demands that the student comes to see that models, like things, are analyzable, challengeable, changeable, malleable, adaptable, generizable, etc. On this view, models are like most toys, gadgets, materials that we can play with in the above manner, but the play must be actively performed with interactive student participation [3, 4] and exploration. This is very important. The pedagogical principle of learning by experiencing, constructing and interpreting leads the mind to form the "space of reasons" that contains the creation of conceptual relations. These involve a feedback loop process between theoretical constructs and experiences (D.Bakhurst, 2001 as quoted in [3]). The important thing for modeling is that models are easier to play with than most concrete objects, because they can be changed at will. I.e., the player/gamer can consider unreal conditions, such as assume unrealistic values of parameters - just for fun, or for curiosity. They can even be simulated for easier processing. Life simulations have been used to teach the Doppler case in a variety of guises and locations [5]. Yes, this play, can be fun and exciting, as most physics [3, 4]. It brings its own reward by means of the feedback loop process to provide the foundation for developing modeling competency. The play with models involves changing contexts, stretching limits, making note calculations on napkins, and even changing the meaning of words along with the contexts. It also involves also making mistakes and corresponding feedback to improve skills and understanding. Just like all creative processes, so physics too involves making mistakes, and these are to be stressed [4]. Playing with modeling as recommended herein teaches students not only to be bold and fearless about

error, but also to be careful and to check their work with reasonableness and consistency checks. The Doppler effect provides an opportunity to teach not only a fundamental law of physics but also the modeling process itself in ways that are fun and relevant to the students. I.e., the Doppler effect model is amenable to a lot of fairly easy manipulations that will lead students in an important, exciting and fun way to realize modeling as an interdisciplinary competence. As shown below, four of the taxa from Bloom's taxonomy guided and progressively developed the material presented herein: Explain / Comprehend, Use/Apply, Analyze/Investigate and Create/Modify.

The Doppler Modeling In Particular The case of stationary source and observers is used to as prior knowledge and to develop vocabulary and concepts of the relevant processes. The graph model is simple to develop. Next, the case of moving source, and moving observer is considered first physically, then graphically in Space-time, and finally mathematically. The simplest such model is a linear kinematics (D = VT) model living in two dimensional space-time graphs, where one axis is the time axis, and the other is the distance axis Bloom's taxa used where: A) Explain / Comprehend: The explanations for the development of the model involve space time graphs, the geometry of parallel lines (these represent the world lines of equi-phases of the wave phenomena), and congruent triangles. The classical Doppler equation becomes a theorem in Euclidean geometry of equally spaced parallel lines being "cut"/crossed by a skew line! The period of the parallel lines is the inverse of their frequency of cutting the time axis. The changed/ shifted frequency is the rate at which the skewed line cuts the parallel lines. That is all there is to stating the simple classical Doppler effect graph model in words! The math model involves translating the words into mathematical symbols. (B) Use/Apply: Use the Doppler effect for distant measurements inferring the velocities of cars on a freeway, or the pulsations of the surface of the Sun, and detecting the rotation of the planet Venus that is perpetually cloud covered, by reflecting radar signals from the opposite rotations at either end. (C) Analyze / Investigate: This first involves the categorization of the Doppler models. Then it involves analysis of the specific models to see how they can be changed, improved, and played with. Next, it involves obtaining theorems about how the data which upstream and down stream observers can deduce when combining their observations. NOTE: This is called "data fusion" and yields much more information to the sharing observers than they could deduce just from data that depends just on measurements that they make only from their own point of view. (D) create/modify The simplest modification is to obtain the frequency shift of the beeps from a fog horn in thick fog. Next to consider the reflection off moving surfaces. Then, kinematics analogy where runners convey information along similar, but not necessarily straight, pathways to the upstream and down stream observers (more precisely, "information gatherers"), where runners running at equal speeds, replace the wave phenomena. (3) Consider an approaching (receding) object, like a train, and model its worldline on a space time graph. The result is that observers see the two ends (back and front end) simultaneous to their senses, but from different times! Ouestion: Why? Answer: The time that the light travels is different from each end. Yet to appear simultaneous to the observer they must reach her concurrently. Even though the "length shift" equations are the same as the Doppler frequency shift equations, the case here only "roughly" a spatial Doppler effect. Rather it is a new entity, one example of a "top case", in Schola Ludus terminology [6] that comes almost naturally with a creative playing with the modeling.

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Inverse Modeling Based on the Doppler Effect

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Abstract

This contribution presents seven student-ready examples of inverse modeling of currently important cosmological factoids as clusters of small "mini-models" that are easy-to-understand at the high school level. Since they are thematically related, student-accessible and fun to reason about, the chosen grouping of models is very effective pedagogically. In fact it is hoped that this set of examples generate intense interest in the Doppler effect, in inverse modeling methods, and in their applications. Even more than in Earth-bound experiments, the data that we obtain from the stars and galaxies needs to be analyzed and interpreted. The seven examples show that evaluations must be made to choose from several possible inferences and/or interpretations. They all assume as prior knowledge (i) that the Doppler frequency shift equations can be solved for source velocity, (ii) that frequency/wavelength shifts can be read from the spectra of light, and (iii) the meaning of redshift and blueshift: (A) shows why dark matter is hypothesized, and describes why some alternative models are currently rejected, (B) Shows how the cosmological redshift can be interpreted either that the galaxies are simply receding, or that the whole space is expanding, (C) shows how inverse models of Lyman alpha forests corroborate that the universe is expanding, a conclusion that Edwin Hubble was reluctant to make in 1929, (D) shows how scientists predict space weather by "seeing" Sunspots through the Sun, (E) shows one popular method for finding extrasolar planets, (F) discusses the rotation rates of Mercury, and (G) discusses the differential rotation of the Sun using the Doppler effect.

The interpretation of data by the Doppler effect involves decision making based on incomplete information: inferring "distant" conditions of the source of radiation based on frequency shifts read from received spectra. For Doppler data obtained from many earthbound systems, the inference can be tested directly during model evaluation testing. In the cosmic case, however, the interpretation of spectral data by means of the Doppler effect calls for more careful considerations even when invoking the Copernican principle that the laws of the Universe are the same everywhere. I.e., the question remains whether the models are being applied outside of their limits of applicability; or whether the extreme conditions of distant stars/galaxies are known and/or considered fully, or whether the cognitive models are adequate. So, the interpretation is open to revision and improvement as tests of consistency and reasonableness are made. [1] gives a more general discussion of inverse modeling.

A Several Doppler effect studies of star motion imply discrepant inferences. E.g., the velocities of galactic orbits of stars as a function of their distance from their galaxy center are too high: they indicate that the mass inside the stars' orbits is much larger than the mass detected by telescopes. So, either Newton's laws of motion are not true "out there", or the law of gravity is not as simple as found by Newton, or corrected by Einstein³. Or, there is more matter there than we have found. In the 1930s Jan Oort, the discoverer of the Oort cloud, named the phenomenon, "missing mass", and Fritz Zwicky, named it "dark matter" – a mass that does not react with light! By plotting many "galaxy rotation curves" (of star velocity vs. radial distance) for many stars and galaxies, Vera Rubin showed that galaxies rotate with such high speeds that we do not know how they hold together against the centrifugal forces. Thus, the existence of dark matter must be inferred as long as other

³ Note for students: the law of gravity is relevant to restrain centrifugal forces, e.g., by equating the forces from the law of gravitation and from F = ma, we can determine the mass of the Sun from the orbital velocity of a planet and its radial distance from the Sun. This idea is used to determine total mass for stars orbiting their galactic center even though the situation is much more complicated by many stars inside the orbit of one star.

models continue to fail evaluation tests. No adequate alternative models are known at present. Modified Newtonian Dynamics, MOND, one such model assumes that for very small accelerations the, F=ma, is replaced by another equation. See [2] for more details on this whole paragraph, and on more insufficient alternative models.

B Einstein's general relativity theory predicts an expanding universe that began with the Big Bang explosion billions of years ago. Do your students know how this can be partially tested? If the galaxies are still all receding from each other, the Doppler effect predicts that light frequencies are redshifted. But, the force of gravity might have reversed the expansion. What is the actual case today? In 1929, US astronomer Edwin Hubble used the spectral analysis of light from each galaxy studied to verify the predicted redshift. This is the cosmological redshift of light from receding galaxies. Hubble's data plot graph shows that, on the average, the redshift of a galaxy is proportional to its distance from our Sun. The main interpretation, using the Doppler effect, is that the Universe is expanding as predicted. Competing alternatives still exist, but they suffered a serious blow when new supporting evidence was discovered, as discussed next. See [3].

C Quasars are distant objects in the early universe that emit extremely powerful radiation with a component having a 121.6 nm rest wavelength, called the Lyman Alpha line after its discoverer. As the light travels from a distant galaxy it passes through intergalactic clouds of un-ionized hydrogen gas. These clouds absorb light at what is in their vicinity 121.6nm. But, according to B, when the light reaches such a cloud, it has been redshifted in proportion to the distance traveled. Sometimes the light passes hundreds of such clouds, and reaches Earth with a spectrum of progressively redshifted dips in intensity to the lower wavelength side of the emitted 121.6nm rest wavelength [4]. This information of cloud distribution in space is consistent with simulations of the evolving universe.

D Doppler frequency shift data shows that the Sun is a vibrating sound ball of plasma whose frequency modes can be measured by the Doppler effect. ESA/NASA have built the SOHO, Solar and Heliospherical Observatory satellite [5]. SOHO can make accurate Doppler shift measurements of millions of points, or patches of oscillating modes on the Sun's near side surface. The conditions observed on the near face of the Sun can be propagated backward to the far end of the Sun where any Sun spots will be indicated because their extremely high magnetic fields cause special conditions (faster propagation velocities) for the sound waves. Thus scientists detect Sunspots almost as they occur, predict high radiation to occur when a giant Sunspot round the Sun's horizon. Then affected operators will cancel space walks, safeguard high altitude electronics from intense radiation storms and divert polar flights to protect flyers from the heightened radiation.

E Doppler effect data analysis shows that some stars wobble back and forth along the line of sight (Earth-to-star). One interpretation is that a nearby heavy planet is causing the star to wobble about the barycenter (center of mass of the star system) according to Newton's third law, and to keep the center of constant. New telescope technology corroborates this, detecting a slight 1% drop in light intensity [6].

F Doppler effect measurements established the first reliable rotation rates estimates for Mercury. Being so close to the Sun, Mercury is difficult to observe long enough to establish its period visually. It is always less than 30 degrees from the Sun. Giovanni Schiaparelli's plausible but wrong inference from incomplete data was not corrected until Doppler radar data become available [7].

G Analysis of spectral data different latitudes of the Sun has established the differential rotation rates of the solar mass. Almost 400 years ago Galileo Galilei interpreted the motion of Sunspots to infer that the Sun rotates, and that the Sun is gaseous due to having rotation periods that are a function of latitude. The Doppler effect confirms this and provides much more information [5, 8].

In conclusion, we can see that the construction and/or selection of inverse models involves the creative technology of decision making – or of design methods as taught in Dutch high schools [9]. [9] describes the design process in a science and technology setting: - analyze the inputs, compose requirements, generate ideas, formulate proposed solutions, develop one or more of them, and finally, test the proposed solutions. For us, inputs = data; compose requirements = describe what is known and what this constraints/limits; ideas = ideas; proposed solution = proposed model; and tests = model verification tests (consistency

with other facts, reasonableness, limitations, error bounds etc) as normally performed on all models to improve them and to increase confidence in their results.

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A Water Model of a Human Eye

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Abstract

The phenomenon of refraction is usually demonstrated with lenses. But very seldom it is properly stressed, that only the change in refractive index is needed for refraction to occur. As a consequence, it is a common belief that only lenses made of special optical glass or optical instruments have the ability to refract the light.

Water lenses are nearly as effective and a very welcome change for the classroom, either as a motivation, as a demonstration to overcome the above mentioned misconception, or as a mind teaser at the end of the lecture. They also offer the possibility of interdisciplinary approach. Using various water lenses it is easy to demonstrate how a human eye works. Experiments modeling eye–lens accommodation, which provides sharp images of near and distant objects, as well as a human eye model, with possibility to visualize vision within healthy and defective eyes, will be demonstrated.

Human Eye Optics

Human eye is a very adaptable and capable optical device. It can provide sharp images of near and very distant objects, in various light conditions. Adequately, its structure is very complicated. Its properties can be seen in Picture 1.

Picture 1: Human Eye properties. (http://hyperphysics.phy-astr.gsu.edu; numerical data from E. Hecht: Optics)



Eye as a whole is a convex optical device, projecting a small, real and inverted image of the surroundings on the retina. Light enters into the eye through the cornea, a transparent membrane which covers the front surface of the eye, passes through aqueous humor and through the opening in the iris, proceeds through lens and vitreous humor, and is finally absorbed in the retina, covering the inner surface of the eyeball at the back.

Majority of the refraction (about 80%), contributing to the formation of the sharp image on the retina, happens in the cornea, since the change of the refraction index (from 1 in the air, to 1,376 in the cornea) is greatest there. Substantial bending again occurs as the light enters the lens, but only about 20% of the total effect happens there. But the lens is pliable and fine focusing and accommodation, which provide sharp images of near and distant objects, happen there and only there.

Accommodation

When the eye rests, the muscles, holding the lens into position, are relaxed, the lens is flattened, the radii and the focal length being greatest. The image of the distant objects is sharp on the retina. When we look at the near object, the muscles contract and the lens is forced into more rounded shape. Its radii and the focal length decrease, providing sharp image of the objects within small distance. This function is crucial for focusing, since the size of the eye and the distance between the lens and the retina is constant.

Malfunctioning Eye

We will focus on two most common and interesting dysfunctions from the optical point of view, nearsightedness and farsightedness. It happens very often, that the sharp image of the object does not fall on the back of eye, the retina. Sometimes it is the shape of the eye, which prevents the forming of the sharp image, and, mostly with aging, sometimes the lens becomes too rigid to accommodate adequately.

Some people can see clearly only the objects within short distances, but not the distant ones. It is called nearsightedness and it happens when the parallel rays from distant objects are focused in front of retina. Glasses with concave lenses help, diverging the rays slightly.

Farsightedness is called the situation, when the rays from the nearby objects are bent insufficiently, and consequently focus behind the retina. The person sees them blurred, while distant ones are clear. Placing a convex lens in front of the eye helps with additional bending of the rays.

Human Eye Model

A questionnaire, given to a first year students at the faculty revealed, that nearly one half of the students has no idea how the light propagates through the eye and how the image is formed. This stimulated us to design a simple model of the eye, as shown on picture 2.

Picture 2: Water model of a human eye. Photo by G. Iskric.



Water model of the eye consists from a semi spherical fish bowl, filled with slightly colored water to make the light ray visible. (A drop of milk in the water also works well.) A piece of cardboard with round hole is added in front to represent the iris. A set of three convex lenses with appropriate focal lengths (depending on the size of the fish bowl) is used to represent cornea and lens together, one for each of normal, nearsighted and farsighted eye. Additional convex and concave lenses are used as "spectacles" to correct the vision. Overhead projector

serves as a light source (object). Picture 3 shows the model, featuring farsighted (left) and nearsighted (right) eye.

Picture 3: Water model of farsighted (left) and nearsighted (right) eye. Photo by G. Iskric.



Modeling Accommodation

Human eye lens provides sharp images of near or distant object (but not simultaneously) by changing the radii. This is necessary because the distance between the lens and retina is constant. It is very important to stress this to the pupils, and perform some experiments demonstrating that before the demonstration of the model.

Two transparent Christmas tree decoration spheres (commonly available at art shops) with different radii and filled with water (which has a refractive index close to that of the cornea and lens) are used to model the lens. A ruler to control the distance, light source (a candle serves well) and a piece of white cardboard for a screen (a retina, actually) are other things we need.

To get the best results, water should be prepared at least a day in advance, allowing the dissolved gasses to escape. Otherwise gas bubbles form on the wall inside the sphere and disperse the light. (This we can use to model cataract, another eye disease.) Sphere is filled with water simply by immersing it completely underwater and closing it there.

When looking at distant objects the eye lens is flat, so we use the flattened sphere to model it. With older students, the radii can be measured and the focal distance calculated. A connection with the diopter, a measure of the correcting power of the eye glasses can also be discussed. With younger students the focal length is simply measured as a distance between the lens and the screen with sharp image of distant objects projected on the screen (see Picture 4).

Picture 4: Lens with smaller radii (a) also has a shorter focal distance than the other (b).

a)



b)

If the distance between the lens and the screen is kept constant, we expect that the lens with smaller radii provides a sharp image of a nearby object, as it bends light rays more effectively as the flat one. The other one, on the contrary, provides a sharp image of a distant object. Using it for explanation of the functioning of the eye, this is how the muscles reshape eye lens to focus images from different distances. Model of accommodation is shown on Picture 5. Note that the distance between the lens and the screen is kept constant.

Picture 5: Model of accommodation, featuring the eye, focused on the (a) near and (b) distant object.



b)



Conclusions

Human body is taught very thoroughly in primary, secondary and high school, but actual functioning of it remains a mystery, according to the students' answers to a simple questionnaire.

Optics is also taught from primary to the university level, but generalization of the principles or using them in a new content is still a goal to achieve. Experiments presented, hopefully, provide an interesting demonstration and a model to help students visualize the process of vision. On the other hand, it helps to show interdisciplinarity of science, its connection to everyday life and its role in meeting our needs.

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Reconstructing the Creature – Exploring design criteria for teaching NOS

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Abstract

This case study explores design criteria for teaching understanding of Nature of Science, implementing salient aspects of South Africa's curriculum reform in rural, disadvantaged schools. Grade 7-9 science teachers carried out classroom activities that model some aspects of scientific research. Learners constructed and described an unknown animal based on pictures of its bones, then reflected on the scientific characteristics of the knowledge they obtained. Learners ought to see that in science, experiments are not the only way to knowledge, furthermore that creativity and imagination play a role in interpreting data and drawing conclusions and finally that one scientific question can have several equally acceptable answers. Data from nine teachers and 79 learners show that lessons ensued in which learners engaged in genuine inquiry and reflected sensibly on scientific processes. Implementing the design criteria resulted in clarity of purpose of the task, independence from subject matter, creative responses to a challenge perceived as attainable, freedom from pursuit of a correct answer or method, and free use of means of expression other than English. Support for teachers on management tasks and provision of ample resources also contributed to coherence between design intentions and actual classroom events.

Introduction and background

In most South African science classrooms questions are given, not generated, answers are transmitted, not constructed, and each question has exactly one correct answer. Understanding counts for less than marks there, and practical work is non-existent (Rogan, 2003). Meaningless, irrelevant subject matter is memorised merely to pass exams. This science is about *having correct answers*. South Africa is far from unique in this respect. Its new post-apartheid curriculum for the subject 'Natural Sciences' attends to the associated problems, e.g. learners should henceforth develop a richer understanding of the nature of science (NOS) (Department of Education, Government of South Africa, 2002). 'NOS', here, refers to epistemology of science, i.e. the purpose, origin and status of scientific knowledge. However the curriculum does not specify *which* understandings of NOS should be taught, nor *how* they ought to be taught. This classroom based, developmental case study explores practicable answers to these questions.

While philosophers of science disagree on many aspects of epistemology (e.g. Chalmers, 1999), Lederman and Abd-El-Khalick (1998) argue that there is sufficient consensus to establish 'understandings of NOS' adequate for secondary school: the ideas that scientific knowledge is "tentative (subject to change); empirically based (based on and derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination and creativity (involves the invention of explanation); and socially and culturally embedded" (p. 418). Research (Dekkers and Mnisi, 2003) showed that South African science teachers have alternative views, similar to those found elsewhere (McComas, 1998). Most believe that science progresses through experiments in which knowledge is proved, so that theories become laws. Experiments then are the sole, reliable basis of scientific knowledge, and proved knowledge is secure, irrefutable, non-replaceable. The possibility of disagreement among scientists about the interpretation of data or the validity of claims is negated. Roles for creativity and imagination, and influences of social and cultural backgrounds of scientists are recognized, but how these roles and influences play out is unclear. On the assumption, to be verified in the study, that learners would share these views, lessons were designed to develop the views that: scientific knowledge is based on various kinds of inquiry, not only experiments; interpreting data and drawing conclusions are not straightforward, depend on creativity and imagination of researchers; there often are several,

contested answers to a single scientific question. Learners first engaged in inquiry, then evaluated their findings in comparison with the work of scientists. The activities provide a starting point for activities towards developing understanding of NOS.

Methodology

Teachers in an in-service program received, for a sequence of 4-5 lessons, a manual (providing guidance on planning, assessment, and language issues) and low-cost materials for a class of 60 learners. The teachers completed, then taught the activities, monitoring learners' views on NOS using an open-ended questionnaire before and after the lessons. Learners received pictures (Figure 1) of a set of bones that, supposedly, were found during excavations. They were asked to reconstruct the skeleton of the creature, then write a story about it (its appearance, diet, habitat, etc.), and finally to draw it. The combination of reconstruction, story and drawing encourages learners to mobilize different aspects of their knowledge about animals, and to express themselves creatively and imaginatively. The task models a scientific investigation, and invites learners to explore the problem collaboratively and in depth. There is no single correct answer yet all serious responses have merit.

The scientific reconstructions from these bones (Figure 2) were withheld until after the lessons so as to keep the learners' inquiry authentic and avoid teaching to the 'correct answer'. However, the scientists' views were important, validating the inquiry as 'science' and showing the scientists' solution – a late-Jurassic, fish-eating pterosaur, with a wing span of about 90 cm, named Scaphognathus Crassirostris (meaning Thick-beaked Tub-jaw).



Learners' reflections on the results of these activities were guided by questions such as what they had done, why, what they had learned, how 'good' the new knowledge was, in what sense they were doing science, and whether their claims held as scientific knowledge. They evaluated whether creativity and imagination were used and explored variations in reliability of their inferences. They discussed related characteristics of scientific knowledge.

The design criteria of Table 1 derive from consideration of the specific circumstances and ideas described above, the research literature on the relation between inquiry and NOS (e.g. Khishfe & Abd-El-Khalick, 2002) and general educational principles pertaining to the importance of motivating and activating learners and enhancing metacognitive understanding. Learners' work was translated by their teachers if it was written in the local language (Northern Sesotho). Teachers kept journals to describe how learners engaged with the activities. One sequence was monitored by the author. Data sets consisted of complete, representative sets from nine teachers and 17 complete groups of, in total, 79 learners. Details on methodology and data analysis are discussed in Dekkers (2006). This paper focuses on a comparison of design intentions with experiences, activities and products.

Results and discussion

Feasibility of the teaching approach – support for teachers

Criteria 2 (c)-(f) deal with assisting teachers in support of their teaching and resource management. Data on whether support was adequate can be derived from teachers' journals.

Table 1. Design criteria for the activity 'Reconstruct the Creature'

Intentions	Criteria applied : The task should
1.	(a) Be perceived as an entertaining, attainable challenge;
Activate	(b) Make minimal demands on learners' (or teachers') content knowledge;
learners:	(c) Be of an obviously (potentially) scientific nature;
shape inquiry followed by	(d) Make use of daily life process skills (that can become the basis for developing scientific process skills);
reflection.	(e) Have no correct answer, nor one that can be memorized or copied from the board;
	(f) Invite and reward creative, divergent and imaginative input;
	(g) Require reflection on concrete, practical issues, naturally linked to the learners'
	(b) Challenge incomplete understandings of NOS (wir that all scientific questions)
	(ii) Chanenge incomplete understandings of NOS (<i>viz.</i> that all scientific questions have a straightforward single correct answer obtainable only through
	experiments and that imagination and creativity have no significant role in that
	process).
	(i) Stimulate cooperation, collaboration and debate on non-trivial on-task issues.
2.	(a) Place minimal demands on English language skills;
Take local	(b) Encourage use of mother tongue and other, non-verbal means of expression;
circumstances	(c) Take over issues of selection of learning objectives, planning, management and
into account:	assessment from the teacher;
teachers,	(d) Remove the problem of lack of resources;
learners,	(e) Provide assistance with issues involving large groups;
resources, habits.	(f) Provide the opportunity to abandon in a non-threatening way the habitual expository, transmission based, teacher-centered approach.

The teachers (Dekkers and Mnisi, 2003) developed most insights they were meant to teach by doing the activities themselves, but remained convinced that only experiments provide the certainty that makes knowledge scientific. Teachers considered the lessons outlined in the materials to be learner-centered, properly resourced, motivating and enjoyable. They appreciated the assistance in planning. Learners were said to have produced creative and imaginative work. The few comments about insufficient class time were contradicted by learners' complete and adequate written responses. Field notes indicated, though, that much time was spent on cutting, pasting and drawing, and relatively little on reflection and discussion.

Feasibility of the nature of activities – support for learners

Criteria 1 (e), (i) and 2 (a), (b) of Table 1 ought to support learners in engaging with the inquiry task in the intended way. Reports on classroom events and learners' products provide information on whether the assistance was adequate.

Teachers reported some language problems, but though some children found it difficult to write a story about the Creature in English, others were reported to have enjoyed the writing. The stories (e.g. Figure 3) suggest that learners may have experienced grammatical problems but were not hampered in expressing their ideas and inferences. The learners' submitted work and the teachers' journals suggested that classes generally stayed close to the lesson plans and design intentions, and that group-work and other suggestions were followed.

Teachers and students responded well to the open nature of the inquiry, as is evidenced in the products. Though the absence of a correct answer received some critical remarks it is a crucial design feature – teachers and students generally lost interest in their own creations once a 'correct' answer was made available.

Design criteria 1 (a), (b), (d), (f) ought to optimize learners' inquiry efforts. Their effectiveness can be assessed based of learners' products: the skeletons, stories, and drawings.



In the task, learners organized data, used existing knowledge to analyze and interpret new data, developed alternative interpretations, established rules for data manipulation, inferred claims from data based on reasoning and debate, etc. Learners' work shows that they used their imagination and creativity to synthesize coherent wholes. In their stories and drawings learners inferred claims about the animal's appearance, movement, diet, etc. All produced a drawing of an animal, including some of the habitat, food, other animals or humans (see Figure 4). Most groups wrote an imaginative essay, of which six were labeled as 'brief', seven as 'rich' (see Figure 3). Skeleton, story and drawing complemented each other in the process.

Design criteria 1 (c), (g) and (h) support learners in reflecting on their findings, and in drawing inferences about 'real' scientific investigations. Data derive from worksheet answers and questionnaire results.

Groups unanimously interpreted the reconstruction as a scientific investigation, but saw scientists as better informed, more imaginative. Learners thought scientists, too, would make

The animal was laying very big eggs and we think Its eggs were stronger than other animal's eggs. Becaus if you can see Its skeleton you can see that the animal was bigger and It is meant that Its eggs were big as we have said. Up to so far we that the animal was the largest animal in the World which was laying eggs. According to our group we think that Its eggs can be 50 cm high. That animal was living on the land and we think It was living next to the water. Because most animal that It is big like our Creature like to live where there is water. The animal like to live where the land is full of trees so that It can take the oxygen from the tree. Up to so far we think that animal was living far away from people so we think that is why there is no person who know or who have seen this animal. According to our group we think that when It was hangry It was eating 2 animals like lion and tiger. So we think this animal was eating meat only. We think this animal is no longer existing. Because we think God made it not to exist.

different reconstructions due to differences in ideas, imagination, and experience. About half the groups agreed that this was not an experiment and yet yielded scientific knowledge but the other half were unclear about the word 'experiment'. Learners were meant to see that they had gained knowledge, but that some of it was less secure, and none of it absolutely certain. At a concrete level this intention was met, e.g. most groups noted that their Creatures had some common features, with more agreement on the function of some of the bones than on others.

After the lessons learners were substantially better able to express views on NOS. Based on pre-post questionnaire comparison (see Dekkers, 2006), as a result of the lessons, learners:

(1) more readily accepted alternatives to experiments to obtain scientific information,

(2) but maintained that only experiments provide secure knowledge.

(3) more readily accepted the role of imagination in science in a wider sense.

(4) less frequently thought that each scientific question has a single correct answer.



Conclusion and implications

Science arguably represents the most reliable, most tested, and most consensually agreed knowledge, and yet contains no absolute truth. Accepted science is reliable and trustworthy, and yet its theories may be replaced. There is no single scientific method, but a methodical and systematic approach is key to science. Science depends on the imagination and creativity of scientists, a universal and objective science cannot exist – but no other knowledge matches science's level of universality and objectivity. Relevance in science depends on one's socio-cultural setting, and yet the same laws of nature apply to us all. Science depends on empirical facts, but facts are partly mental constructs, not entirely externally given. This science is all about *finding and justifying the best possible answers*. Each aspect of this picture may be debatable, but surely it is a richer picture than the one painted in the first paragraph of this paper, encouraging a more inspiring educational practice.

In the activities studied here this richer picture emerged as a direct result of using the design criteria of Table 1. The activities further exhibited teacher clarity on educational objectives, independence from mastery of subject matter, serious work in answer to an attainable challenge, absence of an urge to find the correct answer, and free use of means of expression other than English. Support for teachers on management tasks and provision of ample resources also contributed to success. It will be worthwhile to elaborate the criteria in developing a more complete approach to teaching NOS.

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For information on (NOS activities with) Scaphognathus Crassirostris, see these websites (Figure 2 was taken from sites with * on 3-11-2005): *www.teacherlink.org; dino.lm.com; www.dinodata.net;

*www.freewebs.com; *www.bowdoin.edu; www.enchantedlearning.com; www.pterosaur.co.uk.

Theoretical Model in Teaching Physics: Perspective "Discipline Culture"

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1. Introduction

Peierls (1980) introduced typology of models as used in physics. We suggest modification which reflects the nature of model as a special theoretical construct. Our approach draws on the idea that model mediates between the represented object (phenomenon) and certain system of basic principles (theory). This *first* possible function of model, mediation, follows from the difficulty of any theory to describe real objects.

Moreover, we suggest that relationship between physical theory, model and object is not linear but rather can be represented by means of a semantic triangle: object-sign-concept (Frege 1890). The interrelation object-model-theory is similar (Fig. 1).



Figure 1. (a) Semantic triangle of Frege; (b) Similar triangle: object-model-theory.

The semantic triad of Fig. 1b is silent regarding the sequence of unfolding. This may lead us to another function that model can play when the theory is not known. In this case, a model serves as a device of construction of a new theory. In such a case, the model is heuristic and presents a hybrid of elements from the old and new theories. Such a model anticipates the new theory, guessing regarding its essential features. This is the *second* possible function of a model: a mediator between the new and old theories. The latter function is in fact an important cultural function facilitating the progress of physics. Awareness of the two functions of models suggests implications to physics teaching and broadens the common approach to using models in physics education (Hestenes 1992).

2. Critic of Peierls' typology

The suggested by Peierls (1980) typology of models encloses seven types:

1. Hypothesis. 2. Phenomenological model. 3. Approximation. 4. Simplification. 5. Heuristic model. 6. Analogy. 7. Thought Experiment.

Considering the examples brought by Peierls, we see that models of Rutherford and Bohr are identified as the same type 1. Bohr's model is stated by Peierls to be "a more quantitative version of Rutherford's including the quantum conditions for selecting possible orbits and the rules for frequencies of emission and absorption lines. This is still type 1 model..." (*ibid.*)

It is difficult to agree with this identification since Rutherford's model was totally classical, whereas Bohr's one included quantum postulates: conceptually innovative elements. This fact essentially distinguishes between the two models, suggesting separation in their theoretical affiliation.

It is indeed difficult to distinguish between the types *hypothesis* and *phenomenological model*. For example, in the 19th century several distinguished physicists developed the kinetic theory of gases. Some of them (e.g. Van der Waals) believed that gas (and liquids) presented a system of moving atoms. Others (e.g. Maxwell) considered such a model to be merely a convenient representation. It was unclear, then, which type of model had to adopt atomism. Either classification of this model appeared as subjective.

Furthermore, with regard to *approximation* (type 3) and *simplification* (type 4), Peierls seemingly addressed mathematical procedure in the former and a disregarding of details in the latter. This separation is, however, not strict. In fact, disregarding of details expressed as a mathematical step, presents approximation. This is what happens when we neglect terms in

any expansion in a small parameter. Evidently, approximation is not always justified, but always brings simplification.

Similarly, the separation between *heuristic* model (type 5) and *analogy* (type 6) could be fuzzy as well. Faraday's and Maxwell's models of ethereal media used in the development of electromagnetism had both features. Similarly unclear affiliation may have the model of Drude for electron gas in the old theory of conductivity in metals.

Summarizing, the typology of Peierls is valuable in its representing the variety of functions that models play in physics. The spectrum is broad and deserves reflection in physics curriculum, important for constructing an adequate image of physics.

3. The nature of model

We suggest another typology basing on the nature of model as a mediator between theory (basic principles) and the considered by it objects/phenomena (e.g. Morrison, 1999). In practice, an object (O) can be treated by theory (t), a specific theory which is deduced from the fundamental theory – Theory (T). This mediating relationship might be presented symbolically (Fig. 2a).



Figure 2. (a) Mediating relationship: object-theory-Theory; (b) Semantic relationship: object-theory-Theory.

Such presentation, however, masks the direct relation between Theory and the considered by it objects/phenomena. Therefore, the semantic representation (Fig. 2b) is more adequate. The latter presents a semantic triangle of the type considered in Tseitlin and Galili (2006). In a sense, specific theory represents the object and such a theory is determined by the Theory that provides general conceptualization. We can illustrate specific theory by the electromagnetic theory of light (while the fundamental theory is electromagnetism), or by celestial mechanics (while the fundamental theory is Newtonian mechanics). Specific theories address certain subject domains: light or cosmic objects and should not be confused with models.

Models enter the play when a theory, a subset of the Theory, is not sufficient and one needs additional assumptions, features not included in the theory thus facilitating an account for the object, mediating it to the Theory (Fig. 3). If the case where such a Theory is lacking, we appeal to some theoretical hypothesis.



Model replaces the original object by another (ΔO stands for variation) and might introduce additional theoretical features (ΔT). The need for additional theoretical features destroys the idea of semantic triangle in the sense of Frege (1892), which presumes the *whole* concept to be located in the concept vertex T.

Comparing the triangles Fig. 2b and Fig. 3, we can infer the relationship between model and theory:

$$M(O,\Delta O/T,\Delta T)_{\Delta O=0,\Delta T=0} = t(O/T)$$
(1)

This result means that model coincides with theory (a subset of Theory) when the deviations (ΔO , ΔT) are nullified.

This representation allows understanding of the nature of models and helps to follow up the dynamics of creation of a new theory as Einstein conceived it (Heisenberg 1971):

... although we are about to formulate new natural laws that do not agree with the old ones, we nevertheless assume that the existing laws—covering the whole path from the phenomenon to our consciousness—function in such a way that we can rely upon them and hence speak of "observation".

In our terms, this statement means that despite the innovation of the theory ΔT we introduce, we generally remain within the same Theory T (vertex T in the semantic triangle). This representation visualizes the process when modeling facilitates creation of a New Theory, often starting with making changes in the Old Theory (e.g. quantum Ansatz of Plank to classical theory of radiation). This point seemingly represents the genus of modeling, its conceptual role in physics research.

4. New typology

To construct a new typology of models we start with Peierls' typology and its critique provided above. Thus we suggest three pares: (1) *Hypothesis* and *Phenomenological* model, (2) *Approximation* and *Simplification*, and (3) *Heuristic* model and *Analogy* to identify as three types: (1) Representative-Ontological, (2) Simplifying and (3) Heuristic-Epistemological models, correspondently.

Furthermore, in accord with the introduced interpretation (Fig. 3), we will distinguish between the models M_0 modifying the Object from M_T , those modifying the Theory:

$$M_{O}(O/T) = M(O^{*}/T) = M(O, \Delta O/T)$$
 (2)

$$M_{T}(O/T) = M(O/T^{*}) = M(O/T, \Delta T)$$
⁽³⁾

O* and T* stand for the modified Object and Theory. We thus obtain:

- a. *Representative-Ontological* models of two types: M_0^R and M_T^R ;
- b. *Simplifying* models of two types: M_0^{S} and M_T^{S} ;

c. *Heuristic-Epistemological* models of two types: M_0^{H} and M_T^{H} .

For example:

- a. M_0^R models: Copernicus' model of solar system, Maxwell's ether, Rutherford's atom.
 - M_T^R models: Bohr's atom, Lorentz-Fitzgerald contraction. These models usually anticipate new theory. Often forgotten after the revolution, they posses bricolage nature.
- b. M_0^{S} models: Newton's models for movement of planets, van der Waals equation for gases.
 - M_T^S models: Ohm's and Hooke's laws, Bernoulli's equation (hydrodynamics).
- c. M_0^H models: specific heat model of Einstein, gas as billiard balls. It is important not to confuse these models with M_0^R models.
 - M_T^H models: Ising model for phase transition, Faraday's and Maxwell's etherical models for electromagnetism.
 - Although a particular model may combine several affiliations this does not diminish the importance of clarification of the nature of a particular model.

5. Theories and models in discipline culture

Recently we have introduced the concept of discipline-culture (Tseitlin and Galili 2005). This approach reflected the idea that several scientific disciplines together perform a dialogue regarding the Nature. New disciplines are produced by this reality and there are many interdisciplinary problems. Thus mechanics and thermodynamics together treat hydrodynamic problems; astrophysics unites almost all physical disciplines. This reality makes the simple view of normal science (an activity within a single paradigm, one basic Theory) problematic. Separate isolated *research programs* (Lacatos 1978) may serve only as an approximation. It is more representative to speak about physics research within what we call discipline-culture framework.

As a *research program*, discipline has a nucleus (major principles, concepts) and normal part (applications of the nucleus - body). In addition to these two *a discipline-culture* includes periphery that incorporates alternative conceptions, contradicting the nucleus with regard to the same subject (Fig. 4).


Figure 4. Discipline-culture structure. Models of the type M_0 are located in the body of the discipline and models of the type M_T are located in the periphery.

The framework of discipline-culture may help to represent different types of models. Thus, the more a model emphasizes variation of the *object* than a *theory* (M_0), the closer such a model is to the nucleus and is located in the body. Such is Landau's free electron in a magnetic field, which is close to the nucleus of quantum physics. Lakatos interpreted M_0 models as *protecting belts* of the nucleus, demonstrating their power in predicting and accounting for experimental results. We can add that these models provide *stability* to the discipline-culture against its changes (breakthrough between the periphery and nucleus in creation a new discipline-culture).

However, models are used in physics also as a device for producing new physics. These are M_T models. Plank's model of quanta to account for thermal radiation, Einstein's model of photons to account for photo-effect, Bohr's model for atom to account for atomic spectra, all were models that did not fit any nucleus at the time they were produced. Their place was in the periphery of classical disciplines (Newtonian mechanics, Maxwell's electromagnetism).

In short, M_0 models are mainly useful in application of the known theory. In many cases models of M_T become the major tool of physics. They may stand against the renowned nucleus or with still unclear, for the moment, relationship to them. It is between the two roles of models that demarcation line runs between fundamental and applied sciences. Heuristic-epistemological and representative-ontological models present the working area producing new physics. These models serve an important cultural role of mediators between new and old theories, facilitating heredity in science. Models of M_T types can also serve a shortcut in cases when applying Theory, even if possible, is extremely difficult (e.g. random phase approximation in solid state physics). It is clear that this role is of much practical importance.

6. Implication: teaching physics as a culture

Culture has no internal area; it is all located at boarders, which cross it all over in its every part. Every atom of culture essentially exists at the boarders, which provide it with importance and meaning; isolated from the boarders, it loses the ground, becomes empty, arrogant, and dies. (Bakhtin 1975: 25)

Teaching physics as a culture presumes presenting models in the variety of types and so roles, nature and meanings. The important aspect of such teaching is the fact that models introduce additional features and assumptions not included in the Theory and/or objects/phenomena. These new elements should be emphasized and discussed, facilitating students' meaningful learning of physics.

The important cultural detail is the "boarder location" of M_T type models. In this aspect student attains the perception of physics as a *culture*, that is, as knowledge construct inherently incorporating different views (conceptions, paradigms). There, at the boarder, much (and perhaps the major) activity occurs. This perception holds equally in physics and humanities (Bakhtin 1975).

In the reality of physics teaching we often take the strategy emphasizing rigid structure, not its non-homogeneity. For instance, in our survey of physics textbooks we did not find stating the fact that Lorentz force is not Newtonian. This very fact may stand at the beginning of a different instruction of electromagnetism (Galili & Kaplan 1997), introducing students into the world of relativistic theory. This approach followed Einstein and Infeld (1938) review of physics in which they considered the model of Lorentz force as a construct breaking with the Newtonian paradigm. This book can serve an example of treating physics as a culture, incorporating models as a language and tools. Discipline-culture approach to teaching physics keeps with this tradition and develops it (Galili & Hazan 2004).

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Modeling as a tool for co-operation between physics and other subjects; A course for in-service teachers from upper secondary education

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Abstract

A structural reform of Danish upper secondary education implies that more lessons are set aside for optional subjects organized as subject packages. An important feature of a subject package is that the participating subjects form a coherent program ensured by a closer interaction between the subjects. Some of the subject packages have as their core mathematics, physics, chemistry and biology. To implement the objectives of the reform co-operation across the traditional boundaries between the subjects is required both at the level of subject matter as well as at the level of pedagogy. To prepare the teachers for the reform the University of Southern Denmark developed the course "Modeling as a tool for cooperation between the subjects of the natural sciences". In the course the teachers are introduced to a didactical framework for co-ordination and mutual interaction of the subjects of mathematics, physics, chemistry and biology. As a part of the course the teachers develop and implement integrated modeling instructional units, which are presented at a seminar for teachers.

Introduction

In Denmark a structural reform has been introduced into upper secondary education. The reform implies that students choose among subject packages where the participating subjects form a coherent program. To prepare students for studies in science, mathematics and technology in tertiary education some of the packages have as their core the subjects of physics, chemistry, biology and mathematics. To implement the objectives of the reform co-operation is required across the traditional boundaries between the subjects both at the level of subject matter as well as at the level of pedagogy. Future mathematics and science teachers will need thorough and interconnected knowledge of their subjects. This calls for an in-service teacher training program with the aim of producing teachers who are committed to an increasing understanding of the connections between science, mathematics, and technology.

1 Modeling as a tool for co-operation between the subjects of mathematics and natural sciences

Many mathematics and science educators are in favor of a more realistic education where modeling activities are used to treat concepts in realistic, everyday life contexts [1], [2]. As a rule modeling activities take place in an interdisciplinary context and are therefore a promising frame for elucidation of the relations between mathematics and science. Based on the assumption that models for making sense of complex systems are some of the most important components of knowledge of mathematics and science a team of science and educational researchers from the University of Southern Denmark and teachers from upper secondary schools have developed the course "Modeling as a tool for co-operation between the subjects of natural sciences" for in-service teachers from upper secondary education.

1.1 A didactical model for co-operation between subjects

One of the great challenges of the reform of Danish upper secondary education is the development of integrated learning environments across mathematics and science. Although it's a common view among many teachers in upper secondary schools that closer relations

between mathematics and science should help the students to grasp both mathematics and the subjects of the natural sciences, a better co-ordination and mutual interaction of the subjects is far from being a trivial task. What is needed is a didactical model for integrating productive ideas from a variety of theoretical and practical perspectives on the relations between mathematics and science.

During the course the teachers are introduced to a didactical model for co-ordination and mutual interaction between mathematics and science. The model consists of two phases: *horizontal linking* and *vertical structuring*. In the horizontal phase thematic integration is used to connect concept and process skills of mathematics and science by modeling activities. Also in this phase explicit connections are established between the process skills of mathematics and science. The vertical phase is characterized by a conceptual anchoring of the concepts and process skills from the horizontal phase by creating languages and symbol systems that allow the students to move about logically and analytically within mathematics and science without reference back into the contextual phase. The shift from the horizontal to the vertical phase thus might concur with a shift from integrated instruction to subject-oriented instruction. It should be stressed that the didactical model is iterative. Once the concepts and skills are conceptually anchored in the respective subjects, they can evolve in a new interdisciplinary context, as part of a horizontal linking [3].

1.2 A System Dynamics approach to modeling

In science education it is often accentuated that many phenomena and their patterns of interaction are best described in the language of mathematics, which then becomes a bridge between the students' verbal language and the scientific meaning we seek to express. In the course mathematics plays a central role. In our view the importance of school mathematics should be justified by the fact that it provides the students with powerful tools for dealing with the quantitative aspects of the world. This role is brought about predominantly through the building, employment, and assessment of mathematical models.

When students are involved in modeling activities in an interdisciplinary context they are confronted with information from multiple sources that is presented and communicated in different forms. To avoid the problems brought about by the differences in terminology and notational systems and create a common domain for mathematics and science a System Dynamics approach to modeling is introduced in the course. A system dynamics model integrates and runs all the variables of the system in a dynamic way, which means that students involved in a modeling activity gain practice in identifying and representing variables across the boundaries between subjects.

2 The modeling course

It is the core idea of the course to involve teachers in design, implementation and evaluation of innovative instructional sequences, which deals with a wide range of aspects of mathematics and science. The educational reconstruction model developed by Kattmann et al [4] provides a framework for designing, implementation and validating the instructional sequences. The model consists of three main components which mutually interact: First, analysis of the content structure (including the educational viewpoint); second, the execution of empirical investigations which at first have explorative character; and third the construction of instructional units. These three components are supposed to stimulate each other in an interactive and cyclic process.

The development of the modeling course was initiated in the autumn of 2004 where 12 teachers participated in a pilot study funded by the Danish Ministry of Education. Based on the experiences from the pilot study the first version of the course was developed in the autumn of 2005. The course's objectives were

- to develop prototypes of interdisciplinary instructional units centered on modeling activities and including at least two subjects,
- to encourage the creation of communication between the subjects of biology,
- chemistry, mathematics and physics, and
- to introduce the teachers to the System Dynamics approach to modeling in an interdisciplinary context.

In the spring of 2006 14 teachers with several years of teaching experience participated in the course, which was structured as three sessions: a 3-days workshop, a 2-days workshop and an

open seminar. During the two workshops the teachers were accommodated in a hostel. All the sessions included inspiration lessons by modeling experts from The Faculty of Science at University of Southern Denmark.

2.1 The modeling workshops

The first workshop began with a presentation of the didactical model of horizontal linking and vertical structuring, and the model of educational reconstruction. Then the software Powersim was introduced. Powersim is a tool for System Dynamics modeling. During the workshop the teachers were shown examples of modeling with Powersim and worked in groups with the program.

To effectively create interdisciplinary teaching units teachers from different subjects need to collaborate. Therefore the first workshop was ended with creating 7 interdisciplinary teams of 2-3 teachers representing different subjects. Once the teams were established the members faced the challenging task of designing a scenario for an interdisciplinary instructional unit centered on modeling activities and including at least 2 of the subjects of physics, chemistry, biology and mathematics.

The second workshop was held 1 month after the first. Each of the teams gave a preliminary report about their instructional unit and got comments from the other teams. The participants were also introduced to a guide for reporting on their project. Then the teams had $1\frac{1}{2}$ month for writing a report with a description of their interdisciplinary instructional unit, preparing a presentation of the unit at a seminar, and implementation of some of their ideas in the classroom.

2.2 The modeling seminar for teachers

A factor relevant to successful innovations is the degree to which it is perceived better than the existing program it hopes to supersede. Lesh & Sriraman [5] introduce the main law survival of the useful law that determines the continuing existence of innovative programs and curriculum materials. Usefulness involves going beyond being powerful in a specific situation and for a specific purposes to also be sharable with other people and re-usuable in other situations. It is therefore of great importance to make the improvements available to a larger community of teachers. To meet this challenge the teams presented at the final session their interdisciplinary projects for discussion at an open seminar at University of Southern Denmark attended by 32 upper secondary school teachers. Table 1 below shows the projects presented:

Project:

- Mathematical modeling with Powersim
- Models interplay between reality and simulation
- Data sampling and modeling
- Modeling an inclined throw
- Traffic and kinematics
- Mathematical modeling and enzyme kinematics
- Modeling with dynamic diagrams

Subjects:

- Mathematics and biology
- Mathematics and physics
- Mathematics, chemistry and biology
- Mathematics and physics
- Mathematics and physics
- Mathematics, biology and chemistry
- Mathematics and physics

TABEL 1: Interdisciplinary instructional units presented at the open seminar for teachers

The table shows that there were different approaches to projects ranging from a focus on the software to a focus on the modeling process. Looking at Table 1it is not unfair to say, that the topics of the projects are ones that belong in the traditional content of the subjects. Therefore it is obvious to include a more up-to-date interdisciplinary content including technological and socio-scientific issues in the next version of the modeling course.

After the seminar reports, presentation and lecture notes from the teams were made accessible on a website [6].

Conclusions

Modeling provides a generic methodology that can serve as a common denominator for learning subjects such as physics, biology, chemistry, and mathematics. The teachers welcomed the opportunity to explore new ways to engage students in interdisciplinary modeling activities. There were among the teachers agreement on that the course supported active innovation and intervention in classrooms. The System Dynamics approach was according to the teachers a new way to enhance students' understanding of complex systems and formal thinking. But the integration of System Dynamics into teaching is also challenging and time consuming.

From our experience the course structure with workshops and an open seminar made it possible for the teachers to share their ideas and experiences with their colleagues and having contacts with academic experts in the fields of modeling and educational research. However, to get full profit of interdisciplinary modeling activities further research on the constraints and possibilities of the cooperation between the subjects of physics, chemistry, biology and mathematics is needed.

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Models in physics teaching: arguing a broader view

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"Physicists tend to use models to aid their understanding of complicated physical situations. ... different types of model serve as aids in thinking more clearly about physical problems, ...as steps towards rational understanding of the actual situation." (Peierls 1980)

1. Introduction

Two major trends of the philosophy of science, rationalism and empiricism, coincide regarding the physics knowledge as two folded. Firstly physicists develop knowledge constructs, *principles/theories*, and secondly they *apply* them to account for various phenomena and situations (Einstein 1918, Losee 1989). This was the way of physics, the way of Aristotle, Newton, Einstein, Bohr, among many others. Physics curricula in schools often present physics mainly in the second aspect of this program: application. This misbalance often causes inadequate image of the nature of physics, emphasizing training of application and remaining silent (or being highly naïve) regarding the genesis of knowledge (research activity and scientific literacy in epistemology). One can imagine, however, physics curriculum representing both aspects and using *models* for this purpose. This is because models are used by physicists in both types of activity, application of old as well as constructing of new principles and theories. We will try to present this problem and suggest its solution.

2. Models in normal science and in normal curriculum

Kuhn (1962) described "normal science" as an elaboration of a certain conceptual framework (paradigm) in a sophisticated research activity: "Bringing a normal research program to a conclusion... requires the solution of all sorts of complex instrumental, conceptual, and mathematical puzzles." To a great extent this activity is interwoven with constructing models allowing solving complex problems. Thus, it was the model of gas as particles that allowed to Daniel Bernoulli to apply Newtonian theory to gases anticipating statistical physics of later times. It was Lord Kelvin, who constructed his "innumerable and disparate models" to apply the all-inclusive mechanical explanation of matter (Duhem 1914/1954). We teach mathematical pendulum as the simplest model demonstrating oscillations (Matthews 2000). Faraday's and Maxwell's mechanical models of electromagnetism tried to reduce electromagnetism to a mechanical model of perturbations in the medium of ether (Whittaker 1960).

We see that models served as a way by which physics applied certain known paradigm to solve complex, often very difficult, "puzzles", requiring much effort. "Normal science", as defined by Kuhn, is by far not a simple application of procedures and models, even when the theory is known. Models mediate between the theory and concrete questions regarding reality.

In education, however, we are often pushed to the shortest way to reach easily measurable progress in learning, and represent physics as a collection of models, ready to use procedures. Trying to help students, we are doing our best to represent physics as well organized procedures of algorithmic solving of *standard problems* and accordingly evaluate the result of learning. This is an intention of a regular, "normal", curriculum, and in this it is not similar even to the "normal science" (leave alone the "revolutionary science"), exactly like "puzzles resolving" is not similar to applying algorithm, although both use modeling.

Modeling is sometimes represented in education as a reduction to special cases: uniform rectilinear motion, accelerated rectilinear motion, circular motion, harmonic oscillator (Halloun 2004). The role of theory is reduced to "Laws of change" (Newton's laws) and "Law of interaction" (the Law of Universal Gravitation) *within* a model (Hestenes 1995). Thus theory plays the role of useful rules, normally taking a little, if any, conceptual attention

of the student. Although such an instruction may help in coping with problems of regular tests, it is clear that it changes the Gestalt of physics: emphasizing the instrumental arsenal of physics, "the trees", it forgets the general picture of the Nature – "the forest". Whether this could be considered satisfying depends on the adopted values and goals of the curriculum. The message of such an instruction is that "normal physics" is a tool to solve problems and this craft can be mastered through a careful application of some prescription.

Among other teaching modes are elaborations of physics as a history of ideas about Nature, individual projects, laboratory of guided exploration, physics Olympics, which are closer to Kuhnian idea of "normal science". Modeling in these activities appears as a process of heuristic accounts for a situation. One can get a flavor of such use from Polya's approach to problem solving in mathematics (1945/1973). Polya wrote about heuristic strategies of going to the extreme, changing the symmetry of the problem, replacing the given problem with a similar more familiar one, etc. All these are modeling strategies, since are based on a replacement of one object with another. We may add from physics the simplifying approximations and qualitative thought experiments. Such trends of exploration in physics use modeling as an invention, discovery of an artificial construct apt to replace certain real object or situation. Guiding the analysis seeking such a representative replacement Polya emphasized the encouraging of holistic and inventive thinking about the problem of concern. He wrote: "Think of the man who cannot see the forest for the trees".

In the context of physics teaching, models appear as a means of physics account of the Nature, together with concepts, principles (ontological and epistemological), objects, rules of logic, mathematical apparatus. All these separately present "trees" telling about the "forest" – fundamental theories. Such items as the principle of relativity, the concept of inertia, operational definition of weight (or any other physical concept) enter curriculum being interwoven with modeling. Theory becomes an intricate organism, "a picture of the world", rather than "a collection of models".

3. Taxonomy of models in physics research

Peierls (1980) presented a typology of models in physics including a variety of types. We present them all here, replacing some of Peierls' examples with those more relevant to school physics.

- 1. *Hypothesis* ('Could be true'). [e.g. Different models of atoms, models of solar system, atom-vacuum conception.]
- 2. *Phenomenological* model ('Behaves as if...'). [e.g. Phlogiston, caloric, Maxwell's ether, water and gas models of electricity current.]
- 3. *Approximation* ('Something is very small or very large'). [e.g. The laws of linear response: Hooke, Ohm, Newton; perfect gas, mathematical pendulum.]
- 4. *Simplification* ('Omit some features for clarity'). [e.g. Van der Waals' equation for gas, various models of solar system and planets, Drude's model for conductivity.]
- 5. *Heuristic* model ('No quantitative justification, but gives insight'). [e.g. Einstein model for specific heat, simple model for ocean tides.]
- 6. *Analogy* ('Only some features in common'). [e.g. Water and gas analogies for electrical current, analogy between pendulum and LC circuit.]
- 7. *Thought experiment* ('to disprove hypothesis'). [e.g. Carno cycle, Maxwell's demon, Einstein-Podolsky-Rosen experiment.]

Although this classification can be debated (we made it in the second paper), the list is rich in approaches to complex systems, interpreting them in terms of simpler ones, in order to reveal the features of the former. The list presents variety of functions models play in physics. For example, heuristic models seek a different goal from making approximation; heuristic model may not even pretend being hypothetical: Einstein's model for specific heat did not suggest calculation, but provided a mechanism of decreasing of specific heat at low temperatures. Similarly, Van der Waals' equation was suggested for numerical account of gas and as a heuristic tool, rather than gas depiction (hypothetical function). The fact that the same model can be ascribed, using Peierls' classification, to more than one type suggests that it rather displays possible functions of models than their classification.

Modeling in "normal" physics could be often arranged in a sequence of rising degree of complexity. For example, the models of solar system could start from the sun and point planets, not interacting and moving in circular orbits. Subsequent models include elliptical

orbits, mutual attraction of planets, their spherical shape, satellites and comets. Despite of the rising accuracy, the models remain, however, within the same *theory* of Newton's gravitation. The choice of a model depends on the particular objective faced by the researcher: prediction of eclipse, traveling to the Moon, or else. Importantly, many models quoted by Peierls were different from the latter type. Rather than being logically deduced from the known theory Pierels' models presented the "revolutionary science" (now or in the past), an account of the unknown reality by means of heuristic constructs imitating it. The question is, then, whether we see implications of this list to physics education.

4. Status sensitive teaching

Models massively penetrate to all domains of physics and therefore inevitably present in physics curricula. However, the question remains regarding the way of presentation, whether teaching distinguishes modeling and, if it does, whether the functional type of the particular model is specified. For this purpose, Peierls' classification can be very useful. Models presenting, for example, the special cases of movement, are traditionally considered in the common teaching of motion. This use, however, should not exhaust the image of models constructed by the students. Reduction to the merits of one type would mean to abandon the tradition of using models in a variety of functions in the real science.

In our survey of the popular physics textbooks (we checked about twenty textbooks of introductory course published in English in the past decade), we found that although models are widely presented, there is a general lack of addressing the status of models; the authors are silent on their nature and functions in the particular context. Models often create a perception that they are the theory, or that they are photographic image of reality, which models are not.

We did not see mentioning that Hooke's and Ohm's laws present models of certain type. Different models of atoms are rarely explained with regard to their relationship to reality (beyond the critique of correctness). For example, such presentation of Van der Waals' model may cause a false conception that it presents a literal depiction of gas (balls of a finite size), whereas the author suggested it as a heuristic model and a means of numerical account to replace the model of point masses. No difference is normally made whether the introduced model is deduced from the known theory (such as a uniformly accelerated motion) or serves as a heuristic device in the absence of such a theory (for instance original introduction of photons or matter waves).

Discussion and Conclusion

Much work of physics educators is needed to provide physics teachers with the information regarding the nature and function of models. Currently such information is often not available and not included in the training of prospective teachers. Physics education discourse on modeling is extremely important in this regard, providing a better understanding of physics to the learners. Teaching models with their status and function could improve physics curriculum since it can reveal the nature of physics as a method of knowing. Understanding the role of modeling brings the student closer to both "normal" and "revolutionary" physics. A serious effort of conceptual clarification is required to explain students the relationship between models and theory (principles, laws, concepts). This step could change the image of physics as a discipline, attracting students who are naturally curious regarding the way the Nature is organized. Such an image includes the models which anticipated scientific revolutions.

In a sense, almost all physical statements regarding natural phenomena could be considered as models, being conceptual representations of reality. However, physicists do not do this. They distinguish between *theories, models, principles*, concepts and so on. The core of physics is its theory, which presents the most general and inclusive construct. This picture is differently interpreted by constructivist-empiricists and realists-empiricists, implying different research programs (e.g. Hacking 1983). However, making modeling a sole focus of physics curriculum, moving theory to the shade, neglecting its status as approaching to the Truth about Nature, may change the fundamental values of learning science and hence may reduce students' motivation to learn physics, as something worth to devote the whole life.

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Analysis of Science Students' Views About Models And Modelling

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Abstract

The aim of this study was to gain an insight into the understanding of the (31) physics, (87) mathematics (34) biology and (62) science students, studying at faculty of education, about models which play an important role both in science and science education. For this purpose, a questionaire was developed from Treagust's (2002) research to find out the students' views about what a model is, the role of models in science, how and why models are used and what causes models to change. The students were asked to fill in the questionaire with 31 items; one of them was open item and the others were Likert-type scale. The items of Likert-type were categoriezed under five groups, each one having explicit charactristics, process, examples, uses and changes of models. The student answers were evaluated under the sections "models as multiple representations" (MR); "models as exact replicas" (ER); "models as explanatory tools" (ET); "uses of scientific models" (USM); "the changing nature of models" (CNM) and "examples of models" (ME).

Introduction

The terminological meaning of model and modelling in science is not so narrow in scope as the dictionary meanings of these words. While in science literature modelling is described as all of the processes to make an unknown target clear and understandable depending on the present resources. The product obtained from modelling is regarded as a model. These definitions suggest that in science the limits of modelling and models cannot be clearly determined as is done with word meanings in dictionaries. In fact, the terminological meanings of modelling and model simply summarize the steps the scientists follow to discover new products (law, theory, principle, equations, formula etc.) and the results of these steps within the scope of scientific procedures. The fact that Adams and Le Verier predicted the existence of Uranus which is the eight planet away from the Sun by using a model dependent on the gravity concept and soon after this prediction some further observations confirmed the existence of Uranus or that the atom model proposed for the first time by Thomson was replaced by the atom models of first Rutherford and then Bohr in the light of the recent findings. These two examples may help to understand the use of models, the role and scope of modelling in the discovery of new scientific products. The examples given so far also provides an explanation to the questions why science students should use and develop models in the science classrooms (Harrison, 2001; Van Driel and Verloop, 1999; Harrison and Treagust, 2000).

Modelling and models are indispensable components of the teaching of science. Especially, the abstract nature of science broadens the functions of models and their uses in classrooms. It may be quite difficult to make some concrete concepts accessible and understandable for the students as well as the abstract concepts. For example, electric field lines as abstract concepts or the atom and its structure as concrete concepts are not the concepts students may directly interact with. Such difficulties urge one to produce new solutions to be able to teach these concepts to the science students. That is to say, when one considers that the electric and magnetic field strengths are represented as groups of lines in physics or chemical bonds are represented as sticks and atoms as small balls to explain atom structures in chemistry, the importance of modelling and models becomes clear in the teaching and learning of science (Harrison and Treagust, 2000).

The Groupings of Modelling and Models

It is quite difficult to determine the limits of the scope of a model. Several researchers report that the identification of the characteristics common to all scientific models is more explicative than the

general definition of a model. Van Driel and Verloop (1999) described the common characteristics of scientific models as follows;

- A model is always related to the targets it represents. The target may be a system, an object, a fact or a process.
- A model is a means of research used to obtain some information about a target that cannot be observed or measured directly.
- A model does not interact directly with the target it represents. For this reason, a photograph or spectrum connot be regarded as a model.
- A model is dependent on the analogies suitable to the target and thus enables one to create testable hypotheses about the target. A model always differs from the target in remarkable details.
- The similarities and differences between a model and a target should provide the researchers with the possibility of predictions about the target in the process of creating a model.
- A model is developed as a result of some processes affecting each other mutually and it may be revised in the light of some new studies about the target.

Grouping the models enables us to emphasize the differences between the models. Up to now there have been various groupings depending on some studies; such as scientific and nonscientific models, models according to appearances (abstract or concrete), models according to their functions (identifying-explicative-descriptive). The following is a schematic example of a detailed grouping prepared by Harrison and Treagust (2000).

Fig. 1. A concept map of the typology of concept-building analogical models (Harrison & Treagust, 2000)



Modelling

While the concept of model refers to the product obtained through some processes, modelling refers to the operations used during the procedure. The two main elements of modelling procedure are the source and target. The source includes all of the knowledge and experiences obtained so far. The target is the information that will be obtained by the help of the sources; in other words, it is the knowledge aimed to reach at. With the help of the sources some predictions can be made about the target and their truth could be tested. If the results obtained could explain the target as aimed, the model presented is

acceptable. Otherwise, the present information is evaluated again. However, it shoul never be forgotten that any of the models cannot represent any targets fully. If they did, the model would be the target and there would be no need for a model. Still, the model or models used in certain times to explain a fact may be abondoned or changed in the light of new findings. This suggests the idea that models are not permanent facts (Justi and Gilbert, 2002).

Purpose of Research

It is not wrong to define modelling in general as a scientific thinking and studying. Models are the products of modelling process. It is clear that both the use of models and the modelling process have a central role in the teaching of science. Since the main goal of science teaching is to enable students to develop scientific thinking and skills, students should be helped to understand the nature of models and modelling in the classroom and to make them practice these as individual or group work. The following is the summary made by Justi and Gilbert (2002) about the features of models the students are required to know.

- to learn science: Students should know the nature, function and limitations of main scientific models.
- to learn about science: Students should be able to understand and evaluate the role of the models in the scientific products confirmed, shared and spread by scientific researches.
- to learn how to do science: students should be able to create, express and test their own models.

For this reason, our study deals with the ideas of science students about models and modelling. Our aim is to reveal student views about the roles of models in the teaching of science

Method

The Sample

This study was carried out with the participation of 214 first year students at the Educational Faculty of Gazi, 31 students from physics department, 87 students from Mathenmatics department, 34 students from biology department and 62 students from science department. The students had not taken any courses before about models and modelling. They did the test depending only on their previous experiences.

The questionaire

The first 26 Items of 30 Itemed-testing were taken from Treagust's study (2002). The last four items were added to find out the science students' ideas about scientific model examples. Thus, a Likert-type test of 30 items with five choices for each item was prepared. There were choices labeled as (SD) strongly disagree, (D) disagree, (NS) not sure, (A) agree and (SA) strongly agree and science students were required to choose the most suitable ones for themselves. At the end of the test there were openended questions and some space was provided for the students to write about the examples of the models they had in their mind. The Cronbach alfa (α) reliability factor was calculated as 0,76.

Groups of Items

30 items in the test were grouped so as to determine the students' ideas about what the models are, what roles they have in science, how and why they are used, what caused them to be abandoned or changed and what is a model (Treagust, 2002). This grouping is shown below:

Table 1. Grouping items for objectives

Items	Groups of Items
1-7	MR: Models as multiple representations
8-15	ER: Models as exact replicas
16-20	ET: Models as explanatory tools
21-23	USM: Uses of scientific models
24-26	CNM: Changing nature of models
27-30	ME: Model examples

The items in MR group were prepared to reveal whether students agree that models are multiple representations or not. One of the examples is as follows; Many models may be used to express characteristicss of a science phenomenon by showing different perspectives to view an object (Item-1).

The items in ER Group indicate the perceptions about how much a model can resemble the target it represents. Item-8 that a model should be an exact replica is one of the examples.

The items in ET group are related to the contribution of the model to the students' understanding of any phenomenon. This group covers creating mental models or concrete representations. One of the examples is as follows; Models help to create a picture of the scientific happening in your mind (Item-17).

The items in USM group aim to determine the students' ideas about how models can function besides their roles as descriptive or explanatory. The Item-23 that Models are used to make and test predictions about a scientific event is an example.

The items in CNM group are related to their continuity. One of the examples is the Item-24 that A model can change if new theories or evidence prove otherwise

Finally, the items in ME group are used to determine whether students are aware of the models used in science. The Item-28 that tables, formulas, chemical symbols and schemes are models is one of those examples.

This test aims to find out the limits of the students' ideas about models. The fact that there were more items than only one item with the same aim in the testing groups shows whether their ideas are consistent or not. Item-4 can be put both in MR and ET groups. Similarly, Item-13 and 14 are covered both in ME and ET groups. That some testing items complement each other makes it easy to determine student ideas

Discussion

a) Models as multiple representations (Table-2, Items 1-7)

The alternate models designed for any phenomena provide different points of view and physical images for the happening aimed to be explained. A great number of students agreed on this idea (Items 1-7). The scores in the table indicate that students agree on the idea that a lot of models can be used to express the characteristics of a scientific happening. Besides, students disagree on the idea that a model includes everyting necessary to show or explain a scientific happening (64,1%) and it reveals that students are aware of the fact that there might be some common characteristics between models and the things they represent as well as some other characteristic not shared by them (Item-7). Their awarenes results from the idea that any of the models never represent any facts fully and if they did so, the model woul be the fact itself.

b) Models as exact replicas (Table-2, Items 8-15)

While 66,3% of the students disagree on the idea that models are exact replicas, 23,4% of them agree on and 10,3% of them were unsure of the idea (Item-8). The percentage of the students who agree on the idea that a model should resemble a real object is 21,9 (Item-9). When one considers the representation of electric field lines, it is very clear that a model does not need to resemble the target it

represents. A similar situation is of question for Item-14. 19,2% of the students think that models can represent what the real object is and what it looks like. But, the responses given to items-10, 12, 15 contradict with the responses given to the other items in ER group. It is interesting that 41,1% of the students think models should bear an indisputable resemblance to the real object they represent. The percentage of the students who believe a model should resemble the real object in every ways except from the size is 46,3. 41,5% of the students express models as the reduced forms of objects. Generally, the responses given to the items in ER group indicate that students agree that models should be nearly similar to the fact they represent.

c) Models as explanatory tools (Table-2, Items 16-20)

Students are aware of the role of the models as explanatory tools. The mean values in this group confirm this idea. 87,4% of the students express that models can represent the facts visually or physically. Most of them agree on the idea that models help us to form a mental picture of a scientific phenomenon (Item-17). This item emphasizes the existence of mental models. That is to say, students know that there are some rearrangements in the mind about the fact the model represents and it enables us to evaluate the represented fact from different points of view. In paralel to the responses given to Item-16, 75,3% of the students indicate that pictures, diagrams, maps graphs or photographs can be regarded as models.

d) Uses of scientific models (Table-2, Items 21-23)

The percentage of the responses given to the items in this group indicates whether students have enough knowledge about why scientific models are used. 43,9% of the students were unsure about the testing Item-22 that in order to show how models are used in scientific researches, again models are used. The percentage of the students who were unsure about the other two items also attracts the attentions. These percentages show that some students have some confusions about the nature of models.

e) Changing the nature of models (Table-2, Items 24-26)

A great number of the students share the idea that models can change in the light of new findings (Items-24, 25, 26). This situation indicates that students do not regard models as fixed facts but as the ones that can be changed when needed. But it is surprising that 23,4% of the students agree on and 19,2% of them are unsure about the Item-26 that a model can change when there are changes in findings or beliefs. Similarly, the fact that 21% of the students are unsure about the Item-24 indicates that there is insufficient knowledge about the situations models can change in.

f) Model examples (Table-2, Items 27-30)

54,6% of the students agree that models are used to form theories (Item-27) while 26,2% of them are unsure of and 19,2% of them disagree with this idea. While 61,7% of the students regard the tables, formulas, chemical symbols and schemes as models 24,3% of them reject this idea. (Item-28). But, most of the students agree on the Item-29 that maquettes and toys are models. Yet, 42,1% of them disagree with the idea that Newtonian laws, Archemedes principle, Evolution theory and Pisagor theorem are models whereas 34,6% of them were unsure about it (Item-30). The findings obtained from the responses given to the items in ME group show that most of the students do not have enough knowledge about what examples are included in models.

		_	%			
	Ν	x	(S)	D	NS	Α
MR1 Many models may be used to express features of a science phenomenon by showing different perspectives to view an object.	214	4,359	0,617	1,9	1,9	96,2
MR2 Many models represent different versions of the phenomenon.	214	3,785	0,978	14	11,7	74,3
MR3 Models can show the relationship of ideas clearly.	214	3,869	,0878	8,8	16,4	74,8
MR4 Many models may be used to show different sides or shapes of an object.	214	4,126	0,832	5,6	3,7	90,7
MR5 Many models show different parts of an object or show the objects differently.	214	3,364	1,129	27,6	15,9	56,5
MR6 Many models show how different information is used.	214	3,743	0,946	13,5	15,9	70,6
MR7 A model has what is needed to show or explain a scientific phenomenon.	214	2,486	1,112	64,1	15	20,9
ER8 A model should be an exact replica.	214	2,331	1,228	66,3	10,3	23,4
ER9 A model needs to be close to the real thing.	214	3,579	1,130	21,9	12,1	66
ER10 A model needs to be close to the real thing by being very exact, so nobody can disprove it.	214	2,850	1,298	47,7	11,2	41,1
ER11 Everything about a model should be able to tell what it represents.	214	4,074	0,813	6,6	8,4	85
ER12 A model needs to be close to the real thing by being very exact in every way except for size.	214	3,130	1,187	38,3	15,4	46,3
ER13 A model needs to be close to the real thing by giving the correct information and showing what the object/ thing looks like.	214	4,028	0,949	9,8	4,2	86
ER14 A model shows what the real thing does and what it looks like.	214	3,593	1,060	19.2	10.3	70.5
ER15 Models show a smaller scale size of something.	214	2,967	1,286	40,7	17,8	41,5
ET16 Models are used to physically or visually represent something.	214	4,121	0.830	7,5	5.1	87.4
ET17 Models help create a picture in your mind of the scientific happening.	214	4,317	0,782	4.7	4,2	91.1
ET18 Models are used to explain scientific phenomena.	214	3,789	0,902	12.6	14	73,4
ET19 Models are used to show an idea.	214	3,602	0.957	15.9	15.9	68,2
ET20 A model can be a diagram or a picture, a map, graph or a photo.	214	3.827	0.975	12.1	12.6	75.3
USM21 Models are used to help formulate ideas and theories about scientific events.	214	3,457	1,023	18,3	25,2	56,5
USM22 Models are used to show how they are used in scientific investigations.	214	3.266	0.821	15.9	43.9	40.2
USM23 Models are used to make and test predictions about a scientific event.	214	3,453	1.050	21.5	18.7	59.8
CNM24 A model can change if new theories or evidence prove otherwise.	214	3.831	0.903	8.4	21	70.6
CNM25 A model can change if there are new findings.	214	3.911	0.870	8.4	13.1	78.5
CNM26 A model can change if there are changes in data or belief.	214	3.373	1.105	23.4	19.2	57.4
ME27. Models are used to develop theories.	214	3.383	1.022	19.2	26.2	54.6
ME28. Tables, formulas, chemical symbols and shcemes are samples of models.	214	3,420	1.130	24.3	14	61.7
ME29. Maquettes and toys are models.	214	3,883	0.964	11.6	6.5	81.9
ME30. Newton Laws, Archimedes Principle, Evolution Theory and Pisagor Theorem are models.	214	2,715	1,112	42,1	34,6	23,3
: Models as multiple representations ER: Models as exact replicas ET: Models as explanatory tools USM: Uses of scientific mod	dels C	CNM: Cha	nging nat	ure of 1	nodels	ME: N

Table 2	Statistical an	alysis of science	e students' vie	ews about mode	el and modelling

AR: Models as multiple representations ER: Models as exact replicas ET: Models as explanatory tools USM: Uses of scientific models CNM: Changing nature of models ME: Models examples

 \mathbf{x} : Mean A:Aagree=Sstrongly agree+Aagree NS:Nnot sure D:Disagree=Strongly disagree+Disagree N:Tthe number of participations to servey S: Standart deviation %:Percentage

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Fig. 2. Classified model examples given by science students and the frequency of the examples

g) The findings obtained from the analysis of the model examples expressed by students

The models science students expressed were analyzed and grouped as seen in the above scheme (Fig. 2). Model examples are limited to scale models, pedagocical analogical models, mathematical models, theoretical models and map-table-diagrams. The findings obtained from this part may give some ideas about the consistency between the responses given to items in ME group (Items-27, 28, 29, 30) and the model examples they expressed. Most of the examples given by the students include scale and theoretical models. Most of the examples about scale models are maquettes. This is consisitent with the percentage of the responses (81,9% of them agree) given to Item-29 (maquettes and toysa re models). However, it is possible that students were affected by Item-29 because firstly the test was presented and then the students were required to give model examples. That the number of the examples about theoretical model is very high is misleading because 42,1% of the students strongly disagree on the Item-30 (Newtonian laws, Archemedes principle, Evolution theory and Pisagor theorem) whereas 34,6% of them were unsure about it. The reason why the number of the examples in the theoretical model group is higher than it is in other groups is that these examples (atom models, particle and wave models of light, DNA model etc.) are already called as models in science literature.

It can be concluded that the students who regarded the representations of electric and magnetic field lines and the images of atomic bonds as models (pedagogical analogical models) know more about the nature of models. The same thing can be considered for the students who gave the examples of equations, analogies and F=m.a (mathematical models).

Although the students expressed a lot of model examples included in scale, theoretical, mathematical, map-table-diagram groupings, there were no examples about iconic/symbolic models, simulations, concept process and synthesis models and mental models. While most of the students agreed on the Item-17 that models help us to form mental pictures of the scientific phenomena, it is interesting that no examples of mental models are seen in their expressions.

Conclusion

Our study was designed to determine the views of science students at the educational faculties about what models are, what roles they have in science, how and why they are used, what caused them to cahnege and what are the models. Student views were assessed in paralel to the groupings of testing items.

It is clearly seen that students do not have any confusions about the characteristics of models in MR and ET groups. That is to say, they are aware of the multiple uses of models in science and the use of models as explanatory tools. But it is not the same for the characteristics of models in ER and USM groups because a remarkable number of the students think that models should resemble the real object they represent. Moreover, almost half of them claim that this resemblance should be so great that it could not be changed later. In fact, this makes us think that students have some confusions about the concepts such as models, theories and laws. As a result, they cannot decide what analogies a model should have with the target it represents. Besides, the responses given to the items in USM group lead to the idea that students are not aware of the roles of the models in the discovery of scientific products. The responses given to the items in CNM group indicate that some students regard models as stable facts. The fact that teachers or textbooks writers almost never refer to the models used before and abondoned due to some reasons cause students to perceive the models in this way. Depending on the responses given to the items in ME group, it can be said that students are not aware of the fact that symbolical representations and mathematical formulas are models.

The model examples given by the students are limited to the ones expressed very often. Especially, because most of the students agree on the idea that models should be very similar to the facts they represent, they gave more examples of scale models (earth maquette, building maquette etc.). Similarly the fact that the examples considered as models in science literture are very familiar with the things in their field of study may explain why the number of the examples about theoretical models are so high. The model examples we used in our previous studies carried out with high school students and academicians are almost the same as the ones given in this study.

In conclusion, it is clear that students have some confusion about the nature of modelling and models. This is especially related to the ideas about how much a model can represent the fact and what can be regarded as models. For this reason, students need to know more about the nature of scientific models which are the indispensable part of their learning. Thus, they will have a better understanding of the processes of scientific products and their uses.

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Toward a description of upper secondary physics students' modeling competency

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Abstract

An achievement test assessing abilities to reason scientifically and interchange between representations of physical phenomena was developed to describe physics students' modeling competency. Students' competency is described using four proficiency levels. Results indicate that aspects of the nature of science (NOS) and the learning strategy "elaboration" are positively associated with performance on the achievement test.

Introduction

Physics has a long history of being perceived as the most incomprehensible (Osborne & Collins, 2000) and hardest of school subjects (Orton & Roper, 2000). In physics, phenomena are described using multiple representations (e.g. concepts, graphs and formulas). Dolin (2002) suggests the continuous interchanging between the different representations as an important reason why students perceive physics as so demanding.

Project PHYS 21 set focus on the key competencies empirical-mathematical modeling and scientific reasoning. Schools which took part in the project followed a modified version of the regular Norwegian upper secondary physics curriculum (Angell, Guttersrud, Henriksen, & Kind, 2006). As part of this project the PHYS 21 achievement test was developed to profile physics students' modeling skills and relates outcomes to students' epistemological beliefs, learning styles and use of multiple representations of physical phenomena.

The aim of this paper is, based on the achievement test which was part of the PHYS 21 student assessment program (PHYSAP), to give a description of physics students' skills to reason scientifically and interchange between multiple representations of physical phenomena (graphs, formulas, concepts etc.). These two dimensions are used to describe physics students' *modeling competency*. A glance at students' epistemological beliefs (NOS) and learning strategies and how these relate to performance on the PHYS 21 achievement test is also presented.

Method

Population and sample

Students attending the regular and the modified version (PHYS 21) of the Norwegian upper secondary physics course constitute the target population. All 289 PHYS 21 students at six schools and 240 students at nine other schools were sampled. The sampling procedure makes it impossible to generalize from the sample to the population of all physics students in Norway. The data collected can only describe those individuals assessed, but may offer some insight into physics students' knowledge and learning.

Instruments part A: Unit contexts and item formats

Instruments were designed to collect valid data according to the research question. A field trial had been conducted in 2004 - 2005 to investigate the achievement items' psychometric properties.

Students' views of the nature of science, components of self-regulation and the use of interchanges between different forms of representations during physics lessons were assessed by a questionnaire.

Each assessment item was part of a unit made up of a stem and 3 - 9 items related to the theme of the stem. The stem may e.g. describe a current issue related to scientifically investigable questions in a global (e.g. environmental), social (e.g. power supply) or personal (everyday experiences) context.

Four types of item formats were used. The first type of selected response items in figure 1 is *vector* items. Vector items ask students to agree or disagree on e.g. a set of assertions presented in a table. Students are supposed to select one out of two given choices

for each assertion: "yes"/"no" or "agree"/"disagree" etc. The second type is the *multiple choice* (MC) items which offer four alternatives for the students to choose from. The first type of constructed response items is the *short constructed response* which students respond to by writing a single word or number. The second type is the *extended constructed response* where students have to write an answer over one or more lines in their own words.

Classes	Classes Formats	
selected response	vector	8
	multiple choice	6
constructed response	short constructed response	8
	extended constructed response	7

Figure 1: Distribution of item formats

Students' total score was calculated from response to the 29 items in figure 1. Of these 17 were scored dichotomously, while 12 were scored 0, 1, and 2 points resulting in a maximum score of 41 points. Mean score was 19.6 points with a standard deviation of 6.8 points.

Instruments part B: how modeling competency is measured by PHYSAP

The concept of modeling in PHYS 21 has two dimensions, which directed the development of the assessment items: a representational dimension and a reasoning dimension. The first of these dimensions reports on students' ability to interchange between multiple representations of physical phenomena, while the second dimension measures students' ability to reason scientifically. The five forms of representations taking part of these interchanges are, together with the five scientific reasoning processes, described shortly in figure 2.

The five forms of representations in figure 2a constitute ten categories of *interchanges* between pairs of representations (figure 3a). Each test item assessed one of these interchanges and concurrently one of the reasoning processes (figure 3b). For example, four items assessed interchange between the graphical and the experimental representation (element 1.1 in figure 3a). These items account for five of the points scored on the PHYS 21 achievement test.

Figure 2a: forms of representations

Figure 2b: scientific reasoning processes

Reasoning processes				
<i>Analyze/categorize</i> : Analyze problems and categorize data to determine relationships between physical quantities.				
<i>Generalize</i> : Describe physical relationships using general mathematical expressions and describe shared properties of physical formulae (e.g. linearity).				
<i>Make decisions</i> : Select from alternative solutions and explanations in relation to evidence and data provided.				
<i>Evaluate assertions</i> : Evaluate scientific claims in relation to evidence and data provided.				
<i>Predict; justify; conclude; and, communicate:</i> Make predictions about effects of changes in physical systems, use evidence to justify problem solutions and draw and communicate valid conclusions.				

Figure 3: The representational dimension's ten categories of interchange between pairs of representations (part a). The first digit in the parenthesis refers to the number of items (total 29) and the second to scored points (total 41) across the different categories of test items. Part b summarizes the five process categories of the reasoning dimension. The number of items

Figure 3a	Exper	Graphical	Math	Conceptual
Graphical	(4,5)			
Math	(1,1)	(6,10)		
Conceptual	(3,4)	(8,11)	(2,3)	
Pictorial	(2,3)	(1,1)	(1,1)	(1,2)

and scored points are reported in separate columns.

		1
Figure 3b		Points
Analyze/categorize	5	6
Generalize	7	10
Make decisions	5	5
Evaluate assertions	7	11
Predict; justify; conclude; communicate	5	9

Analyses

Sampling procedures decide the inferential statistics used when analyzing data. In this study it was not just convenient, but necessary to study subjects in naturally occurring groups, or clusters. Distribution-free techniques, so-called non-parametric tests, were used solely as such tests do not presuppose a normal distribution of randomly selected individuals.

Likert scales (Crocker & Algina, 1986) with four and five numerical values were used for all single items in the questionnaire. Each single item represents a discontinuous ordinal variable and was for this reason analyzed by comparing observed and expected count using Pearson Chi-square test.

Results

Defining proficiency levels

The representational and reasoning dimensions were merged into a combined scale reporting on students' modeling skills. The score on the scale is interpreted to represent degree of competency to model physical phenomena.

Four proficiency levels were empirically defined on the basis of student performance. The divisions between the proficiency levels were chosen to be as close as possible to the following distribution of students: 10%; 25%; 30%; 25%; and, 10%. The intermediate level, level 2, was designed to be symmetric around the mean score. In practice level 2 accounted for 31% of the students, while level 1 (low) and level 3 (high) accounted for 24% of the students each. Only 8% of the students were assigned level 4 (advanced), while 13% were consigned to the "below level 1" group. Students who do not reach level 1 should not be interpreted as having no modeling skills at all, but they have severe difficulties in applying the multiple representations and reasoning skills considered necessary to acquire understanding of physics.

Anchoring at proficiency levels

Each item was assigned a p-value (percentage correct response) at each of the four proficiency levels. If at least half of the students proficient at a certain level complete an open

constructed item, the item is said to "anchor" at that level. Pure guessing makes it 25% probable that a student chooses the key response on a 4-choice MC item. A 4-choice item therefore anchors at a proficiency level if 62.5% (50 + 50/4 = 62.5) of the students tick off the key response (Crocker & Algina, 1986). Items anchoring at the same level thus lie in the same difficulty interval.

Example of item

The following item is taken from the unit "Sea level" which raises an environmental issue in a "global" context. The origin of the stem is "some students" who want to examine how the melting of ice around The South Pole and in the areas around The North Pole influence sea level. The stone in glass 2 represents the territories covered with ice at The South Pole (figure 4). The item assessed interchange between an experimental and a mathematical representation of the phenomenon. The pictures of the glasses were used to extend and explain the experimental representation. As the mathematical representations were articulated through general mathematical expressions, the item was categorized as a "generalization" according to the reasoning dimension. Approximately one-third of the students answered this item, which anchored at proficiency level 2, correctly.





Example of verbal description of a proficiency level

Items anchoring at a certain level have equivalent difficulty and the proficiency associated with that level is described as a summary of what these items require (figure 5). These summaries thus make it, to some extent, possible to describe what students at each proficiency level "can do". Students at a specific level not only possess the skills associated with that level but also the expertise entailed at levels below. The description in figure 5 reflects the skills assessed by the items anchoring at proficiency level 2 and are related to both the representational dimension and reasoning dimension.

Level	Dimension	Description
2 Intermediate	Representational	Interchange between few forms of representations simultaneously, i.e. the line of arguments includes few steps. These interchanges may include first order but no second order mathematical representations. (Relate $y = ax + b$ to changes in physical <i>systems</i> , link $y = k$ to constant graphs and formulae as $F = ma$ and $F = qE$ to straight lines passing the origin).
	Reasoning	Analyze experimental data to test hypothesis; express experimental situations using general first order mathematical representations; and, evaluate straightforward assertions.

Figure 5: Characteristics of items anchoring at proficiency level 2

Discussion: can physics teachers do something to make a difference?

This report does not claim to provide underlying links between what teachers do and how their students perform, but by identifying factors which interact to influence performance some clues about factors related to success on the PHYS 21 achievement test may be presented to physics teachers and teacher educators.

The importance of being self-regulated

The multifaceted construct "Self-regulated learning" has been defined and described in different studies (see e.g. Boekaerts, 1999; Pintrich, 2000). The PHYSAP instrument operationalised among others the learning strategies *memorizing* and *elaboration*. Frequent use of elaboration strategies has a tendency to be positively associated with performance on the PHYS 21 achievement test.

The construct *elaboration* is derived from responses to items asking for the frequency with which the student *relates new physics knowledge to: prior general knowledge; prior knowledge in physics;* and, *prior knowledge in mathematics.* How new physics knowledge might be used in the "real" world was also part of the construct. The Likert scale 1= Almost never; 2= Sometimes; 3 = Often; and, 4 = Almost always were used for all items operationalising the two learning strategy constructs.

The importance of possessing sound epistemological beliefs

The concept of "nature of science" (NOS) has repeatedly been described in the literature (see e.g. Abd-El-Khalick & Lederman, 2000; Lederman, Wade, & Bell, 1998). The PHYSAP instrument assessed some primary components of NOS using a questionnaire. Students were asked to consider more than 30 statements regarding science's tentative; creative; empirical; and, objective nature. Students' beliefs about scientific laws, theories and models were also explored. Displaying sophisticated NOS-views correlated positively with elaboration strategies.

It is not an easy task to decide whether *knowledge about science* activates *elaborating strategies* or if "clever" reflected students develop proper and consistent ideas about science as they gain insight into science's products (i.e. scientific concepts, laws and theories) and processes (i.e. science's methods, techniques and procedures). An important part of project PHYS 21 was to make students work scientifically and build "mathematical models" (i.e. make mathematical representations from experimental data) of physical systems and thereby gain insight into science's processes and secondly arrive at more sophisticated epistemological beliefs. Data do not imply such relationships as very few items measuring knowledge about the nature of science correlate "strongly" with PHYS 21 attendance. Epistemological beliefs may however assist physics students' assessing their own learning assuming "proper" ideas about science have been taught and acquired.

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Integrated Laboratory Activities with Measurements, Data Analysis and Modeling in Introductory Physics

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Abstract

In this work is presented the combined use of experimentation and modeling an Introductory Physics Laboratory. The course consists of a series of lab sessions, structured in a coherent way, where students perform activities that gradually guide them from taking data measurements and graphing them to advanced data analysis tasks and to mathematical modeling. Application of the course has shown that students' ability in successful modeling tasks can be reinforced by an intermediary step where data analysis tasks are introduced between data measurement and modeling.

Introduction

Over the past two decades there has been a constantly increasing interest in investigating the role of models in physics education research. Several authors highlighted the importance of modeling activities during instruction for all levels of physics education. A number of studies were also carried out on the combined use of experimentation and modeling activities during instruction, and the impact on meaningful learning in physics (Schecker, 1998; Rogers, 2003). Application of theory principles for model building and their extension (mathematical modeling) that constitute the substance of scientific thought and work can become the key to an effective Physics teaching (Harrison, 2000). As results of such application of modeling show, the physical content of laws seems to be thus better understood. Furthermore, a combined use of modeling and experimental process can serve all three axes that Physics teaching has to face: learning of science, learning about science and learning to do science (Hestenes, 1987; Mäntylä & Koponen, 2003).

Research on long-term effects of computer-aided modeling for improved qualitative understanding of key concepts has given promising results. Several studies across Physics curricula showed that modeling could help accentuate the conceptual structure of a physical domain (Schecker, 1993; 1994; 1996). Though it enlarges the set of phenomena that can be dealt with in school towards more complex and realistic examples, Newtonian mechanics is presented as the ideal selection to test the effectiveness of teaching with modeling, while other thematic areas require students' high scientific perception (Hestenes, 1992; Schecker, 1993).

According to Stratford (Stratford, 1996), research on learning processes through computeraided modeling is directed in three types of learning via modeling: use of simple simulations, creation and use of mathematic models using suitable software and creation of simulations using special computer language. Bibliography therefore shows that students' interaction with models of real phenomena, whether we refer to simple use of simulations or to creation and application of new models, gives them the chance to confront their misunderstandings and build on the comprehension of Physics concepts.

Bearing in mind the importance of the combined use of experimentation and modeling an Introductory Physics Laboratory course was designed introducing students to modern ways of doing physics. The course consists of a series of lab sessions, structured in a coherent way, where students perform activities that gradually guide them from data collection/measuring and graphing to advanced data analysis and mathematical modeling. The course involved first year university students of Physics and provides evidence on the impact of the use of laboratory activities that incorporate data measurements, data analysis and modeling on Introductory Physics.

Structure of the course

Introduction to Computers Applications in Physics is a Lab-based course addressed to 1st year students of the department of Physics-AUTH aiming to students' introduction to basic

concepts and their familiarization to the use of Computers in Physics. The one semester long course covers the topics:

- On the structure and compute operation
- Windows and Internet
- Word processing
- Data processing and scientific graphs
- Data analysis and mathematical modeling (Mathematica)

Fig. 1: Home page (calendar) of the courseware material for year 2004-2005



The course is structured in 4-hour lab sessions, which run in weekly basis. Two ICT-labs, 16 PC each, are available for students' work. The course, recently re-structured within **"ePhys project"** makes intensive use of ICT; in the new course-structure, students are gradually introduced from data-measurements to data graphing, data-analysis and finally to mathematical modeling. Course re-structuring was two-fold, using blended learning approach and context-based structure:

- A course web-site was developed, and courseware material was available to students over the internet
- VideoJavaLab (VJL), a web-based application for video measurements, enabled students take their own measurements at each lab. Student exercises were restructured based on the actual data measurements collected.

Courseware material, delivered electronically, consists of two parts

- *VJL-lab*, a web-based lab exercise on video measurements (fig.2), along with a short text description of the Lab activity
- Lab Instructions, in pdf file format (fig.3), accessed through "instructions" tag

Courseware requirements for blended learning applications

There is an increasing demand for university and college courses to be made available online and 'delivered' electronically, taking advantage of the time and place flexibility this approach offers (Collis & Moonen, 2001; VanSchaik et al, 2003). Appropriate online activities are provided enabling students to work as individuals and as members of a team (Salmon, 2000; Salmon, 2002). These activities often involve problem-solving, creation of essays and/or web-reports, and participation in computer-conferencing events. In order to assess students' progress and to certify the skills and knowledge they have acquired, a range of different assessment metrics has to be put into place.

For a realistic blended learning application and course on-web delivery, designing should take into account factors like low speed Internet connections and size of transferable data. Courseware material was structured in html pages, and pdf was the format for instructions. Since the core of the course is based on Video Measurements, an innovated approach was taken to handle and deliver the required videos





A typical video has several MB size in **avi** format; even if converted into **mov** format, size is still too high for any realistic application. In a video-measurement lab, students should be able to go back and forth in frames, repeat and correct measurements, and correlate measured points with data graph-representations (Beichner, 1990; Gamboa et al, 2001). These requirements, call for a new approach in the design of a web-based video measurement lab.

- The interface should be kept simple and developed in java language, to be accessible to students at remote access, through java-aware browser in their home PC.
- Videos for measurements should be kept as small as possible. The selected 320x240 pixels video size gives adequate resolution to measurements leaving enough space for comments and short instructions in the html page.
- Video *avi* (or *mov*) format was converted into filmstrip (sequence of individual frames); VJL applet advances the frames at given frame-rate to simulate motion. Changing typical video format into filmstrip has reduced video size to typically 50KB, realistic for web-delivered courseware material
- VJL applet should be scriptable, to easily incorporate different videos, according to teaching/learning requirements.

Course applications and results

The course is fully implemented since 2003. Initial tryouts were applied in previous years to identify critical conditions for a successful implementation. VJL and courseware materials were installed to an apache-based server where students had free access. During the 4-h long lab sessions students used:

- The VJL web video-measurements to collect data
- Data graphing and Data analysis software, available as stand alone applications
- MS Word to structure their report

Each student was working at his own PC; however, PCs were arranged in clusters of 2 or 3 to facilitate student-student interactions. In the lab-time, the instructor was at first giving an introduction to the subject, mainly pointing out the problem students had to deal with, and the strategy to apply. Students were then left to work alone, deal with the problem, take measurements, make required graphs and analysis, and pre-structure their report. Students had to finish their lab-report and handle it printed on next session. The instructor acted during the course as a moderator.

Fig.3: Typical screenshot of lab instructions (Lab-1) in adobe-pdf.

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Course sequence consists of 8 lab sessions, Introductory Lab and final Lab-exams included. Courseware material is summarized bellow:

- <u>Introductory Lab</u>: Introduction to the Lab and Lab-facilities. Students work in simple problems (free body diagrams) and are also introduced to measurements in VJL.
- <u>Lab 1:</u> Familiarization with MS-word and report writing. Students study the motion of a cart on inclined plane. In their report they include measurements (table), and a screenshot of their VJL experiment.
- <u>Lab 2:</u> Introduction to data graphing. Students study the motion of a real car in the street, introduce their data to data-graph software and get X(time) graph. In their report they include measurements (table), a screenshot of their VJL experiment and the X(t) graph.
- <u>Lab 3:</u> Introduction to data analysis. Students study a projectile motion and make the X(time) and Y(time) graphs of the motion. They introduce their data to data-analysis software (dPlot) to evaluate the equations of motion. In their report they include measurements (table), a screenshot of their VJL experiment, the X(t) Y(t) graphs and data analysis to extract the equations of motion in the two directions.
- <u>Lab 4:</u> Introduction to data simulation. Students study the oscillatory motion of ball attached to a spring, and make the Y(time) graph. They introduce their data to Mathematica, and simulate the motion numerically. In their report they include measurements (table), a screenshot of their VJL experiment, the Y(t) graph data and numerical simulation
- <u>Lab 5</u>: Introduction to data modeling. Students study the motion of a ball in free-fall, and make the Y(time) graph. They introduce their data to Mathematica, and model the motion in first principles. In their report they include measurements (table), a screenshot of their VJL experiment, the Y(t) graph data and numerical model of the motion.
- <u>Lab 6</u>: Introduction to advanced modeling. Students study the motion of a pendulum, and process data to make the Theta(time) graph. They introduce their data to Mathematica, and model the motion in first principles. In their report they include measurements (table), a screenshot of their VJL experiment, the Theta(t) graph data and numerical model of the motion.
- In <u>lab-exams</u>, students were asked to study the motion of falling body in air. Exams had two parts At the 1st part, students were asked to take measurements, graph and analyze their data. At the 2nd part, students were asked to model the motion of a parachutist and calculate the limiting velocity. Students were also asked to make a small 2-page report in MS-word.

Fig. 4: Extract of the final exams, the motion of a parachutist (Screenshot of in adobe-pdf).



The main findings from the first applications are outlined below:

- Student-student interactions during the course were found very crucial, as students could help, guide or learn from his/her peers. Gender differences and PC pre-familiarization were strongly minimized after first lab sessions.
- Each student had a domain account and could use any of the PC-terminals in the Labs. Soon after the first labs students preferred to group up, and work together
- Students' groupware work was also extended to cases outside the lab, when they had to work-on and finish their lab-report.
- Mail-exchange and in-person meetings were ways students adopted for out-of-class collaboration.
- Web-available courseware material enabled students examine the activities for next lab well in advance. This approach much helped students to achieve better scores, and motivated them a lot.

Concluding Remarks

Students –at least in Greece– when entering University have a very limited, if any at all, experience in lab, lab-work, lab-measurements, and lab-report writing. Situation appears similar in many other countries and, in several projects (eg. LabWrite 2003), students need guidance and support in their steps to effective and efficient lab-report writing, data evaluation, and drawing of sound conclusions from the performed analysis. Based on the evaluation of lab-reports, we noticed a positive effect of the various steps of modeling, successively enhanced from Lab-report 1 to Lab-report 6. The experience of "report writing" should also not be neglected; a "maturing" on writing and clearness in argumentation is noticeable, often found in students on later years of their studies.

As computer technology has become an all-pervasive force virtually affecting all aspects of human endeavor - particularly people's ability to observe, think and express the outcomes of their thought processes, we need to continuously review our teaching and learning approaches (Barker , 1998). Two significant trends are currently taking place: the more extensive use of electronic course delivery for providing educational opportunities and the growing use of computer-based products as communication mechanisms. Undoubtedly, such products can significantly influence the speed of communication and the richness of what can be said. Laboratory activities integrated with Measurements, Data Analysis and Modeling in an Introductory Physics course, may prove as a valuable pathway for helping students' scientific literacy, communicating facts and ideas, and, most important, stimulating them for the rest of their studies.

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Models of Science and Scientists in the Literature and among Contemporary Learners

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Introduction

Models of science and scientists were investigated during the last 50 years among learners, pre-service teachers and acting teachers, most of them concerning the scientist's appearance and social abilities (Mead & Metraux, 1957; Beardslee & O'Dowd, 1961; Sagan 1995; Song & Kim, 1999 ;Rubin, Bar & Cohen, 2003). The scientist is depicted as a white male wearing a white laboratory robe, working alone in the laboratory, using conventional equipment dated from the end of the 19th to the early 20th century. He has a high cognitive abilities: intellegance and diligence: "working for long hours". Generally, he has no social abilities and is interested in "domains that no logical man is interested in". In this research we tried to validate these images using different tools.

Very few studies have examined student's perceptions of the role of scientific achievements in society, and what should be the connections between the scientific community and the government (e. g. Stoker & Thompson, 1969; Aikenhead, 1987). Fleming (1987) investigated this issue using general statements that had to be confirmed or rejected and then explained. Checking the relationship between science, society, and government and the threat or progress perceived in science and technology were carried out in-depth in this investigation.

The uniqueness of this study is the investigation of emotional aspects adheres to science and scientist in our society during the history - some of them positive, others expressing suspicion and fear.

For that purpose investigation of the scientific images which appears in classical creations since the 18th century till the 20th century, was made. These images were compared to the scientific images of temporary participants. An in-depth study as done here has not yet been carried out either in Israel or abroad. Some of these images have developed into social myths and symbols, leaving their mark on our attitude to science (Haynes, 2001). For this reason this study is important.

Method

The research was carried out in two stages.

- 1. A survey of creations since the 18th century, both books and films, which expresses emotional attitude toward science.
- 2. An empirical investigation of contemporary learners views about the science and scientists images.

Population and samples

The sample consisted of 131 participants coming from six groups. Five groups of high school pupils (125 participants, 54 male and 71 female), 76 of them were of religious back-ground and 54 of secular back-ground. All the high school pupils are of high achieving back-ground. The study was completed with 6 teacher student, five females and one male.

Description of the study and its tools

The study was a mixed qualitative quantitative study. It consisted of a questioner that contained both open and closed question. The questioner was aimed at finding the attitudes of the participants towards scientific research and technological tools, useful but also threatening, the relation between society-government and science supervision The open questions contains episodes taken from the surveyed literature, or ideas that appeared in them, to check views towards moral issues which confront scientists.

The questionnaire was presented to the high school pupils as a written test, and in an oral mode to the teacher students. The other two tools were a group discussion on the moral image of the scientist influenced by a movie (Frankenstien), and an open essay about the images of science and scientist. The problems that appeared in these tools were aimed to create conflict, and indeed resulted in contradictory answers as will be explained latter.

Results

Models of Science and Scientist(s) in Popular Science and Classic Literature

Models described by classical writers reflect fear and resentment against scientific knowledge:

1. The scientist is disappointed with science; he feels that he had wasted his life in a pursuit after something that cannot be found in the formal knowledge. In his pursue after another kind of knowledge the scientist chooses to make an agreement with the devil and he is doomed. This model is suggested by Goethe in *Faust*. (Stern, 1818)

The scientist is irresponsible about the out comes of his research causes damage to the society and to the environment. This was clearly evident in *Jurassic Park* (Spielberg, 1993).
Some research should not be carried out it is against religion, dangerous, offend the people or impractical (Brecht, 1955).

4. The scientist who is emotionally detached

The three scientists in the famous play The Physicist (Dürrenmatt, 1988), present an image of scientists alienated to human lives and feelings. Their abilities are strictly analytical.

5. Scientists misuse the products of their research: to do evil, use these products as weapons, use them for revenge or since they are avaricious. (i.e. *20,000 miles under the water*, Verne, 1869).

6. The mad and dangerous scientist

The image of the mad scientist emerges from the "Frankenstein experiment" (Shelly, 1818). Frankenstein is the scientist whose ambition cannot be controlled. He ignores the warnings of others, "behaving as god", and creates a living creature.

7. Science and scientists are impractical. This image portrayed by Swift (1726) who denied the usefulness of science in regulating our lives.

8. The scientist has no social abilities, science is detached and uninteresting. The scientists of Laputa (Swift, 1726) are having "supreme thoughts, till they aren't able to talk and hear others".

The authors mentioned above are reflecting these emotions of fear and resentment regarding the scientific ideas, scientific inventions of their time, and some of their uses: since Galileo dispute about the solar system cosmology that clashed with the accepted views of his time, and was considered against religious faith (Brecht, 1955). It continues with Merry Shelly who warned against some uses of electricity (Shelly, 1818). Misuses of chemistry and optics were found in Wells and Stevenson novels, and the fear caused by the manifestation of the nuclear power in the form of the nuclear bomb was described in the play the Physicist by Durrenmatt (1988). Today's authors such as Le Carre (1999) and Crichtone (1993) speak about the dangers and miss uses of Bio-technology and the corruption of the drug corporations.

The model of science in popular science books is different from the unfavorable descriptions sited above. The scientists are praised as working to fight disease and develop science (*Microbe Hunters*, Paul De Kruif, 1926). In books written by acting scientists the hard work of the scientists, the need to scale and rescale the instruments, the caution needed in order to conclude and generalize are described. But, on the other hand the beauty of science and its rewards are emphasized (Smoot, 1993). In one of these books a scientist who prefers a scientific theory different from his own was described. This scientist changed his views since he was convinced that the other theory describes the experimental observations better than the interpretation that he firstly suggested to them in his own theory (Shapley, 1967).

Contemporary learners views about science

The scientist image

The students' perception of the scientist was mainly positive. As in previous research, they think that the scientist is intelligent, diligent and dedicated to his work and has the ability to resist social pressure. In the written assay a more complex image is found. The image of the scientist ranges from friendly and sociable to frightening and having a very strange personality: "his wisdom can lead him to undesirable results".

The progress and the threats of science

The participants have mixed views about the progress and the threats of science. Almost all of them support the research on the prevention of diseases. The conception of utility was their most common rationale. Other reasons given for supporting some research disciplines are interest and enjoyment and the resultant knowledge from the field of research. Rejection of some scientific research (like astronomy and geology) was justified by the grounds that it is impractical. The participants are pro-technology as regards to transportation accessories and they oppose weapons and nuclear reactors which they regard as harmful

The relationship between science, society, and government

Half of the participants believe that the scientist's report of his finding is influenced by economic, personal or a combination of factors. Others feel that every case stands on its own merits: as the accuracy of the report depends on the scientific field, and the social responsibility of the scientist who carries out the research. More than half of the students feel that a scientist should not be under pressure to advertise his discoveries. Scientists and government should work together to determine the field of research, always keeping in mind its benefit for the individual. The scientist's professional motives should be considered; with the advancement of research and the progress of humanity are very important targets of scientific undertaking, even if the individual can be harmed in the process. Some said that the agreement of the scientist. But others opposed sacrifice of life under any circumstances.

Identification of participants with some images mapped in the classical and popular book creation and their moral response

A group of high school students from the main research population watched the movie *Frankenstein* and discussed his image. Most of them opposed this experiment (creating a living creature from pieces of dead bodies). They objected to the idea that a human being can create life, because it goes against God's laws and human reason. The participants felt that the researcher's (Frankenstein) behavior "borders on madness". Several of them emphasized his lack of responsibility toward the creature he created. Many opinions, regarding Frankenstein behavior, were ambivalent: "he has good intentions, but his performance was bad". But they thought that: "real scientists are reasonable"

Comparison between the images that were mapped in the creations and those given by the participations

Comparisons between these two sources show that fears expressed in classic works since the 18th century, were expressed by students of the 21st century. Students are sensitive to the negative and ambivalent images of science revealed in the literature. This concern nuclear reactors, evolution, bio-technology and virus research in general. A big difference was noted between the practical attitude toward knowledge shown by students, and the image portrayed by Swift (1726) who denied the usefulness of science in regulating our lives. Swift's unsocial and unemotional scientists who: "have such high level of thoughts that they aren't able to talk or hear what the other is saying" appears in our participants views: "on one hand, his (the scientist) actions are designed to improve mankind's condition, and on the other hand you have to doubt his functioning as a human being".

Conclusion and implications

This study is about the perception of students towards the morality of science and scientists. It is a pioneer study. Its main recommendation is to strengthen the validity of the results through additional studies and extending the questionnaire. It is recommended to perform an additional study, among other population groups.

It is important to offer the option of regarding science as interesting beyond the efficiency of research as a source for developed technology, or as a means for curing disease. We suggest exposing students to science-related works, similar to those analyzed in the creations analysis. Popular science books, written by the researchers themselves, will introduce the students to real scientists and their work methods. The collective interview method was found to be

particularly suited to the special population that took part in most of this research. This method should also be adopted for instructing a more extended population whose characteristics are similar to those of the main research, and used for discussing ethical and complicated issues.

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Using simulations in physics education

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Abstract

Most of us use information technology every day. This technology is used in physics education, too. The use of computer simulations seems to be one of the most effective ways to use information technology in physics education. By simulations we can study many situations in different initial conditions. Thank for this feature we can explain to students a lot of physical phenomenon more accurately. That is why we try to incorporate simulations in physics education.

This paper will present one of the ways to apply simulations in a classroom. We will present a set of computer simulations in the area of Radial gravitational field and instructions on how to use them. The simulations were designed to fit the curricula and textbooks used at Slovak grammar schools. Teacher's and student's guides were prepared for each simulation. The teacher's guide contains suggestions for possible learning activities and problem tasks for students. On the other hand, the student's guide contains instructions on how to perform the simulation and additional questions for students. The structure of the student's guide is designed to enable students to make hypothesis, observe, analyse obtained data, interpret results, etc.

Introduction

At present, in conferences and seminars there are often allegations that physics knowledge of students is frequently trivial and soft. Most students don't have exact conception of physics effects. Their understanding ends at word definitions and they cannot connect learnt physics effects with situations of real life.

One of the reasons is poor clarity of taught physics which causes insufficient understanding of given subject. For students physics effect presents only equation in textbook and they often don't see connection between school physics and real life.

Due to these reasons many teachers try to find suitable means for teaching by which it is possible to explain given subjects more exactly. One of such means is simulation. On the Internet and in literature there are plenty of simulations suitable for teaching of different physics subjects. However, problem is to use these simulations properly so that they help students to comprehend the discussed physics.

In order to achieve the desired teaching effect, it is necessary to make a few steps before using the simulation by which the teacher prepares students to appropriate use of simulations. After finishing the work with a simulation it is necessary to analyse obtained data and interpret results with students. The individual phases of this process are described in more detail below.

1. Motivation – the use of example from real life or demonstration of a real experiment can be used before manipulation with simulation (in this case the simulation should serve for complementing the information about observed physics effect).

2. Identification of the problem – identification of the problem from motivation presented at the beginning, which is necessary to solve.

3. Formulation of the problem – exact formulation of the problem.

4. Formulation of hypothesis – making hypotheses and seeking for the solution of the problem.

5. Acquaintance with the simulation environment – it is necessary that the students learn to use the simulation environment before the actual activity. Otherwise they may encounter problems when using it.

6. Manipulation with the simulation – students can change initial conditions in the simulation with the help of control elements.

7. Interpretation of results, conclusions – obtained data are analysed and discussed; conclusions are drawn.

8. Transformation of results to original – application of the obtained results to original object; discussion about external conditions which could have influenced this situation in real life.

If the mentioned phases of the use of simulation are followed it is possible to state that this kind of simulation use supports development of creative skill of students. Simulation can be used as a problem task, too. Students can change initial conditions of simulation and following their knowledge try to answer the question: "What happens if ...". Here is a place for students to be creative and produce many answers to the question. They can confirm their statements with the help of simulations.

Following personal experiences the use of student's and teacher's guide seems to be optimal for effective use of simulations. Structure of these guides follows mentioned phases of the use of simulations and it is shown below. Whereas only a sample of student's guide is a part of this article, individual items of the structure of teacher's guide are described in more detail.

Student's guide Title of simulation File name What to do How to work with the simulation Questions for you Additional questions and tasks More to explore

Teacher's guide

Name of simulation File name

A comprehensive curriculum –list of subjects in which the simulation could be used.

Purpose of the simulation

Look at Student's guide

Description and control of the simulation – detailed characteristic of the simulation and description of all possibilities which the simulation offers. Information is supplemented by description of all buttons and control elements which are parts of the simulation.

Set of initial parameters – information about initial parameters; this information is useful when the running of simulation is too quick or too slow.

Student's activities – list of activities for students which they can practise during manipulation of simulation.

Conclusions - brief conclusions which result from the simulation.

Related simulations - list of simulations which are related to the subject.

In the next part simulations in the area of Radial gravitational motion are presented (They are designed in Interactive Physics). Brief description is listed at each simulation. Because of a limited place a sample of student's guide is presented only with the first simulation.

Computer simulations of Radial gravitational field

Is a planet able to change trajectory of the satellite moving around it?

Fig. 1. The motion of the planet and the satellite


The simulation (Fig. 1) introduces a process of gravitational interaction between the planet and the satellite. Speed buttons allow for changing of speed of the planet (the bigger blue object) and the satellite (the smaller red object). A plot of speed vs. time presents how the gravitational field of the planet influences satellite motion. The simulation shows that the gravitational field of the planet causes a change of satellite trajectory and speed.

Sample of student's guide

Is the planet able to change trajectory of the satellite moving around it?

File's name: !satelit.ip

Do you know how it is possible that satellites launched from the Earth and aimed for exploration of farther parts of our solar system have enough energy for this long journey?



What to do

You can find the answer by this simulation which contains two moving objects. Blue bigger object presents a planet and red object is a satellite. By control elements it is possible to change the velocity of both objects. Change of velocities is visible on a plot of speed vs. time. Trajectories of both objects are recorded, too.

How to work with the simulation

- Button START start of the simulation.
- Stop of the simulation click anywhere on the area of simulation.
- Button NULOVANIE (Reset) before the next start of simulation **IT IS NECESSARY** to reset the initial conditions.
- Button ZMAZAŤ STOPU (Erase track) erasing of trajectories of both objects.
- Button POHĽAD ZO SLNKA (View from the Sun) view of moving objects from the Sun
- Button POHĽAD Z PLANÉTY (View from the planet) view of moving objects from the planet.
- Control element RÝCHLOSŤ PLANÉTY [m/s] (Velocity of the planet) changing of planet velocity in the interval <10, 20> ms⁻¹.
- Control element RÝCHLOSŤ SATELITU [m/s] (Speed of the satellite) changing of satellite velocity in the interval <0, 5> ms⁻¹.

Questions for you

- Describe the interaction of the planet and the satellite.
- We talk about the interaction of the planet and the satellite. Why don't we observe a change of planet trajectory after the satellite approaches the planet?

Additional questions and tasks

Explain how is the interaction of a planet (for example Jupiter) and a satellite moving to the further part of our solar system used in real life.

More to explore

Motions of planets of our solar system is presented by simulation called "Motions of the planets of our solar system"

The circular and the escape velocity



The notion of circular and escape velocity is presented in this simulation (Fig. 2). The simulation contains the Earth (a big blue object) and a satellite (a small red object). Before the start of the simulation the user can set the initial velocity of the satellite by the speed button (red). In the plot of velocity vs. time which is a part of simulation the user can observe the change of speed as a function of the distance between the satellite and the Earth.

Why it is possible to see only one part of the Moon from the Earth?



Fig. 3. Why it is possible to see only one part of the Moon from the Earth?

This simulation (Fig. 3) should be used as a problem task for students. They try to find an answer to the question (*Why it is possible to see only one part of the Moon from the Earth?*) which is a part of the simulation. The simulation contains the Earth and the Moon. A white radius on the Moon marks opposite side of the Moon which is not visible from the Earth.

Conclusions

These and many other simulations together with their student's and teacher's guides were used in the classroom. From personal experiences it is possible to conclude that the use of simulations with guides helps students to work more actively and supports developing their creative thinking. In the classroom simulations should be used together with real experiments (traditional or supported by computer) because it is not the function of simulation to substitute real experiment but to serve as its complement.

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Getting Drunk and Sober Again

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Abstract

Students can be provided insight into processes of enzyme kinetics and physiology via compartmental models. Graphical modeling software supports this. In this paper we will discuss various models that students could implement and use to investigate blood alcohol concentration after consumption of one or more alcoholic drinks. Results from these computer models are compared with measured data that were obtained with breath analysis equipment. The broad range of models for intake and clearance of alcohol in the human body ensures that students have great opportunity to practice evaluation and revision of their models. They can develop the critical attitude that is necessary for successful modeling of biological, chemical or physical phenomena. All models presented, ranging from the simplest linear elimination sophisticated physiologically model to а based 5-compartmental model, are used in pharmacokinetic studies. This implies that the students' investigation work is not only fun to do, but also resembles professional research practice.

Introduction

Alcohol is widely used by secondary school pupils. Some facts about Dutch pupils (NDM, 2004; NDM, 2006; Monshouwer et al, 2003; Pol & Duijser, 2003): 90% of fifteen-year-old pupils have ever drunk alcohol, 52% is doing this on a weekly basis, 63% of them have got drunk once (33% every month), and two-third of the children of this age who are out socializing prefer to drink alcoholic drinks (especially breezers and beer) instead of long drinks. 50% of fifteen-year-old pupils consume every week. 6% of juveniles (male and female) of age between 12 and 17 can be considered heavy drinkers, i.e., persons who consume six or more glasses of alcohol on one or more days per week. Binge drinking under adolescents is not unusual anymore, especially during school holidays (in a recent survey at youth camp sites boys are reported to drink on average 17 glasses per day). It is difficult to prevent teenagers from experimenting with alcohol; most pupils consume their first alcoholic drink between the age of 11 and 14. The number of children who go into a coma because of severe alcohol abuse and who are taken into hospital is growing fast in the Netherlands. Pediatricians gave the alarm about this disturbing trend and warned that it will not take long before children will get killed. The Dutch current affairs program NOVA on the 19th of April 2006 drew people's attention to this subject. The pediatrician Nico van der Lely of the Reinier de Graaf Gasthuis in Delft said in the television program: "Annually between five hundred and one thousand children are taken into a Dutch hospital because of alcoholic poisoning." Since 1999 he has noticed in his hospital that the number of hospitalizations has been multiplied by sixteen. It involves particularly girls of age between 12 and 14, who consume in short time a huge amount of alcoholic drinks, especially mixed drinks. Van der Lely: "You must think of one to one and a half liter of alcoholic drinks within two hours." The situation of alcohol usage among secondary school pupils in the Netherlands is not unique: data from other Western European counties, Australia and the United States of America give the same picture of alcohol consumption under adolescents. But compared to many countries, alcohol consumption among school-goers in the Netherlands is high and frequent. Only for the measure 'drunkenness', they score less highly.

Alcohol poisoning occurs when the blood alcohol concentration and hence the alcohol concentration in the brains becomes so high that you can get senseless or even can go into coma. A person can get alcohol poisoned at a blood alcohol level of 4‰, i.e., after more than twenty alcoholic drinks in a few hours time. There is a good chance that the drunken person gets unconscious and is in danger of losing his or her life. At a blood alcohol level of 5‰ a person runs the risk of getting into a coma. Eventually the nervous system is stunned to such an extent that the respiratory system gets paralyzed and the person dies. Teenagers, but also their parents seem to realize insufficiently that alcohol is a poisonous substance that can be damaging. One quarter of the young drinkers of alcohol are of opinion that it takes at least 10 glasses to get drunk (boys: 39%; girls: 15%). Only 11% thinks that four drinks or less suffice. If teenagers (and their parents) would realize

how easily one gets drunk and how long it takes before alcohol is removed from the human body, they might think twice before turning to alcohol abuse and they might be more careful in participating to traffic after consumption of alcoholic beverages.

In this paper we will discuss various mathematical models that secondary school pupils could implement and use to investigate blood alcohol concentration (BAC) after consumption of one or more alcoholic drinks. BAC must be understood as the total amount of alcohol (in gram) in the body divided by the total amount of body water (in liter). All models originate from professional research on alcohol metabolism and are in mathematical terms compartmental models, which can be studied on a computer for instance by using a graphical modeling environment. With computer models, pupils could investigate various scenarios of alcohol consumption: Does it matter in the long term whether you drink fast or slowly? Does it matter whether you consume drinks after a meal or not? Do there exist ways to speed up the clearance of alcohol from your body? Are there gender differences in alcohol intake and clearance? And so on. This type of work gives the pupils a broad idea of alcohol pharmaco-kinetics and it provides them with examples of compartmental models that can also be applied in investigations of other biological, chemical, and physical processes.

But not only mathematical models serve this purpose: conclusions could also be drawn and would make stronger impressions on pupils from data collected with breath analyzing equipment. Such data are anyway useful in discussions of the various mathematical models, not in the least to remind pupils of the fact that not understanding of the mathematical models is important, but understanding of the phenomenon under investigation, even under circumstances that measurements of the biological processes in the human body are complicated. Our own test data were collected with the Dräger Alcotest 6510, which has an accuracy of 0.017‰ within the range of measurements (Dräger Safety, 2006). Breath alcohol measurement can be used as a reliable estimate of blood alcohol concentrations since the 1970s and the accuracy of the equipment used means that it can be reliably applied in clinical studies. However, a recent technical design project (Killian & Kerkstra, 2003) shows that pupils could build their own breath analyzer from a suitable, low cost gas sensor and use the professional equipment to evaluate or calibrate their own alcohol tester. Finally, this paper gives an impression of the possibilities of graphical modeling, and in particular the modeling environment of Coach 6 (Mioduszewska & Ellermeijer, 2001).

Mathematical Models of Alcohol Metabolism

First we will give a review of mathematical models found in the research literature that discusses what happens after alcohol consumption. The range of models give a good view on issues that concern researchers who try to model clearance of alcohol from the human body [see (Lands, 1998), (Weathermoon & Crab, 1999), and (Swift, 2003)].

Widmark model

Widmark (1932) developed the first model that predicts the blood alcohol concentration after consuming alcohol. It is still much used in forensic research because it works well with real data for a large range of values. This model is in fact an open 1-compartment model with a zero-order elimination process: it is assumed that the alcohol after consumption is quickly taken into the body and spread over the total body water, i.e., is distributed rapidly into the

bloodstream from the stomach and small intestine, and further into the watery fluids in and around somatic cells. Alcohol does not dissolve into body fat. Hereafter, the alcohol in the human body is assumed to be eliminated at a constant rate. The whole process is schematically drawn in Figure 1.

After absorption of alcohol, the blood alcohol level is represented in the Widmark model by the formula

$$BAC = \frac{D}{r \cdot W} - \beta \cdot t ,$$

where *D* is the amount of alcohol consumed (in gram), *r* is the so-called Widmark factor, *W* is the body weight (in kg), β is the rate of metabolism (clearance rate in g/l/h), and *t* is the time (in hours) after consuming alcohol. The rate of alcohol



metabolism is individual (for example different for occasional drinkers and alcoholics, men and women, and age dependent), it depends on circumstances (for example before or after a meal) and it varies from 0.10 to 0.20 g/l/h. The Widmark factor is also individual and depends mainly on body composition. Mean values are 0.68 for men with standard deviation 0.085 and 0.55 for women with standard deviation 0.055 (the lower value for women is explained because the female body contains in general a higher percentage of body fat and therefore less body water than the male body). The product $r \cdot W$ is equal to the volume of distribution V_d , i.e., the theoretical volume of the total body water compartment into which the alcohol is distributed. It is considered in most pharmacokinetic models equal to the total body water. Various methods can be found in the research literature to estimate the Widmark factor or the volume of distribution from variables such as height, weight and age. For example, Seidl et al (2000) gave the following formulas:

$$r(\text{men}) = 0.3161 - 0.004821 \cdot W + 0.004632 \cdot H$$

$$r(\text{women}) = 0.3122 - 0.006446 \cdot W + 0.004466 \cdot H$$

where H is the body height (in cm). Assuming a percentage of 80% water in blood, Watson et al (1980) determined various linear regression formulas. Two of these formulas, in which AGE is in years, are:

$$0.8 \cdot V_d(\text{men}) = 0.3626 \cdot W - 0.1183 \cdot AGE + 20.03$$

$$0.8 \cdot V_d(\text{women}) = 0.2549 \cdot W + 14.46$$

Hybrid, open 1-compartment model with zero-order elimination

In reality it takes some time before consumed alcohol get distributed in the total body water compartment. You can deal with this explicitly in the formula of the Widmark model: for example, BAC = $D/(r \cdot W) - \beta \cdot (t - 0.5)$ expresses a time difference of half an hour between consumption and absorption of alcohol. A more reliable method is the following (Lotsof, 2003): Assume that alcohol intake is a first order absorption process and that clearance is linear in time, just as in the Widmark model, then the blood alcohol concentration is given as:

$$C_0 + \alpha \cdot \left(1 - H(t - t_0) \cdot e^{-k_a(t - t_0)}\right) - \beta \cdot t,$$

where C_0 is the BAC at time t = 0, α is a constant proportional to the amount of alcohol consumed at time t = 0, k_a is the absorption coefficient, t_0 is the

retardation time for absorption, and *H* is the Heaviside function. This formula can be rewritten for $t \ge t_0$ as:

 $BAC = B \cdot e^{-k_a \cdot t} + A - \beta \cdot t ,$

where k_a is estimated (Hahn et al, 1997) at 0.08 min⁻¹ with standard deviation 0.03, which corresponds with a half-time of 8.7 min, for drinking with an empty stomach. t_0 is estimated at 1.6 minutes with standard deviation 0.5. A third way of dealing with delayed absorption of consumed alcohol in the body in a mathematical model is to assume that absorption of a dose *D* takes a certain amount of time T_0 (say 30 minutes) and that alcohol distribution in the total body water compartment during this time interval happens at

constant speed D/T_0 .

Wagner model

The third model that predicts the blood alcohol consumptions comes from Wagner (1972). Like the Widmark model it is an open 1-compartment, with the only difference that the clearance of alcohol is now described by Michaelis-Menten kinetics (see Figure 2). This means that after absorption of alcohol, the rate of change in blood alcohol concentration is given by the following





formula:

$$V_d \cdot \frac{\mathrm{d}}{\mathrm{dt}} \mathrm{BAC} = -\frac{v_{\mathrm{max}} \cdot \mathrm{BAC}}{k_m + \mathrm{BAC}},$$

where V_d is the volume of distribution of the total body water compartment (the total amount of body water), k_m is the Michaelis- Menten constant, and v_{max} is the maximum disappearance rate. In Figure 2 we use the clearance factor CL that is associated with Michaelis-Menten kinetics. For a high value of BAC we have that the value of the clearance rate CL is almost equal to the maximum removal rate v_{max} (\approx 140 mg/min) and the graph of BAC vs. time looks like a straight line. Curvature in the graph becomes noticeable when BAC reaches half of the maximum removal rate. At this point BAC = k_m and this value is mostly taken between 5 and 50 mg/l.

Norberg 2-compartment model

Norberg et al (2000) used a 2-compartment model consisting of the central compartment, which is in this case the plasma and the tissues that are in rapid equilibrium with it (liver and kidney), and the peripheral compartment, which contains the rest of the body fluids in other tissues. From the central compartment there is parallel alcohol clearance through the liver following Michaelis-Menten kinetics and through the kidneys (unmodified alcohol in urine) following a linear first-order kinetic process. By the way, only a small portion of the consumed alcohol (2-5%) is excreted in breath, sweat and urine. We denote the alcohol concentration and the volume of the central and peripheral compartment by C, V_C and by C_T , V_T , respectively. The increase in the amount A_u of unmodified alcohol in the urine is determined by the elimination constant CL_d . The distribution of alcohol over the two compartments is determined by the intercompartmental distribution parameter CL_d . The relation

$$CL = v_{\rm max} / (k_{\rm m} + C)$$

corresponds with Michaelis-Menten kinetics. So in this pharmacokinetic model, the following equations hold after absorption of alcohol in the central compartment:

$$V_{C} \cdot \frac{dC}{dt} = -CL \cdot C - CL_{d} \cdot C + CL_{d} \cdot C_{T} - CL_{u} \cdot C$$
$$V_{w} \cdot \frac{dC_{T}}{dt} = CL_{d} \cdot C - CL_{d} \cdot C_{T}$$
$$\frac{dA_{u}}{dt} = CL_{u} \cdot C$$

Norberg and colleagues came to the following parameter values in clinical trials with intravenous infusion of alcohol and via analysis of blood samples at various times:

$$v_{\text{max}} = 95.0 \pm 25.1 \,(\text{mg/min}), \quad k_m = 27.0 \pm 18.9 \,(\text{mg/l}), \quad CL_d = 809 \pm 232 \,(\text{ml/min}),$$

 $V_c = 14.5 \pm 4.3 \,(\text{l}), \quad V_T = 21.2 \pm 4.4 \,(\text{l}), \quad CL_u = 3.65 \pm 2.04 \,(\text{ml/min}).$

Norberg 3-compartment model

Norberg (2001) extended the 2-compartment model to a semi physiological 3-compartment model consisting of the central compartment, from which alcohol is eliminated via urine, the liver, in which alcohol is metabolized following Michaelis-Menten kinetics, and the peripheral compartment (see Figure 4).



This model takes into account that alcohol can distribute directly through the hepatic portal vein from the gastrointestinal tract into the liver so that a portion of the consumed alcohol can be eliminated before the alcohol is distributed via the blood stream to other fluid parts of the body. By the way, this so-called 'first-pass metabolism' is not undisputed. Some researchers [see (NIAAA, 1997), (Lim et al, 1993), and (Ammon et al., 1996)] are of the opinion that enzymes in the stomach play an important role, while others [see (Levitt, 1996) and (Levitt et al, 1997)] are of the opinion that the liver is the most important place in the first-pass metabolism. In all research work is concluded that under normal drinking behavior first-pass metabolism contributed only for a small portion to the total clearance of alcohol.

In the Norberg 3-compartment model we have the following equations after intravenous administration of alcohol:

$$\begin{aligned} V_c \cdot \frac{dC}{dt} &= \frac{D_{\inf}}{T_{\inf}} - Q_H \cdot C + Q_H \cdot C_H - CL_d \cdot C + CL_d \cdot C_T - CL_u \cdot C \\ V_H \cdot \frac{dC_H}{dt} &= Q_H \cdot C - Q_H \cdot C_H - CL_H \cdot C_H \\ V_T \cdot \frac{dC_T}{dt} &= CL_d \cdot C - CL_d \cdot C_T \\ &= \frac{dA_u}{dt} = CL_u \cdot C \end{aligned}$$

Here, D_{inf} is the given amount of alcohol, T_{inf} is the infusion time, and the term D_{inf} / T_{inf} in the first equation is set to zero 0 for t > T_{inf} . C_H is the concentration in the liver compartment, V_H is the liver volume, and Q_H is the liver blood water flow rate. is The liver clearance rate is given by Michaelis-Menten kinetics:

$$CL_H = v_{\max} / (k_m + C_H).$$

The following parameter values can be taken (Norberg et al, 2003):

 $v_{\text{max}} = 89 \pm 18 \text{ (mg/min)}, \quad k_m = 2.9 \pm 5.1 \text{ (mg/l)}, \quad Q_l = 1100 \text{ (ml/min)}, \quad V_l = 1.1 \text{(l)}.$ It follows that the value of v_{max} is close to the value in the 2-compartment model, but that the

It follows that the value of v_{max} is close to the value in the 2-compartment model, but that the parameter k_{m} strongly depends on the model choice. This parameter value turns out to depend much on the value of Q_{H} .

Pieters 3-compartment model

Pieters et al (1990) also modeled alcohol clearance with a 3-compartment model. However, their model considers the central compartment, in which alcohol is metabolized following Michaelis-Menten kinetics, the stomach and the small intestine. The alcohol goes into the stomach first, hereafter into the small intestine, and finally from there it is absorbed into the bloodstream and rapidly distributed over the central compartment. Figure 5 illustrates the model, in which the volumes of distribution of the compartments are not specified, but hidden in the parameters.



The model equations are:

$$\frac{dC_1}{dt} = -\frac{k_1}{1+a \cdot C_1^2} \cdot C_1, \qquad \frac{dC_2}{dt} = \frac{k_1}{1+a \cdot C_1^2} \cdot C_1 - k_2 \cdot C_2, \qquad \frac{dC_3}{dt} = k_2 \cdot C_2 - \frac{v_{\text{max}}}{k_m + C_3} \cdot C_3,$$

with initial conditions
$$[C_1(0), C_2(0), C_3(0)] = [C_0, 0, 0],$$

where $C_0 = D_0 / V$, the initial amount of alcohol D_0 , divided by the volume of distribution V of the central compartment, and where C_1 , C_2 , and C_3 are the alcohol concentrations in the stomach, small intestine and central compartment, respectively, related to the volume of distribution of the third compartment. Tabulated parameter values are (Pieter et al, 1990):

		Mean Values		
Parameter	Dimension	Men	Women	
$v_{ m max}$	$\mathbf{g} \cdot \mathbf{l}^{-1} \cdot \mathbf{h}^{-1}$	0.470	0.480	
k_m	$\mathbf{g} \cdot \mathbf{l}^{-1}$	0.380	0.405	
C_0	$\mathbf{g} \cdot \mathbf{l}^{-1}$	0.455	0.703	
k_1	\mathbf{h}^{-1}	5.55	4.96	
k_2	\mathbf{h}^{-1}	7.05	4.96	
а	$l^2 \cdot g^{-2}$	0.42	0.75	

Table 1. Parameter values for the Pieters model.

The first differential equation in the Pieters model, which models emptying of the stomach, does not represent a simple first-order process, but a feedback control is built-in that depends on the instantaneous concentration in the stomach, $C_1(t)$. The parameter *a* in the quadratic term of the denominator determines whether gastric emptying is faster (negative *a*) or slower (positive *a*) than the first order rate k_1 under normal conditions. So, the effect of an empty or full stomach on alcohol clearance can be taken into account mathematically (Wedel et al, 1991). By the way, food promotes alcohol clearance, even when alcohol intake takes place via

an intravenous infusion (Hahn et al, 1994). The Pieters model cannot explain this.

Physiologically based modeling

Umulis et al (2005) described a model of five organ compartments that exchange material. The compartments are the central compartment, stomach, gastrointestinal tract, liver, and muscle. The scheme in Figure 6, taken from the original paper, describes the exchange of alcohol between the compartments. All compartments, except the liver, are modeled as stirred reactors; the liver is modeled as a tubular flow reactor. The stomach in this model contains zero tissue water volume and only the volume of liquid contents V_S (alcoholic bever-



age), which is absorbed into the gastrointestinal tract in accordance with a first-order process of which rate constant k_s depends nonlinearly of the amount D of alcohol consumed. The delayed absorption of alcohol is described by the constant k_d , which is equal to 0 for $t > T_0$ for a given time interval T_0 (the term $k_d \cdot T_0$ is usually chosen smaller than the dose D). The equation is:

where

$$\frac{dV_s}{dt} = -k_s \cdot V_s + k_d ,$$

$$k_{\rm S} = \frac{\kappa_{\rm Smax}}{\left(1 + a \cdot D^2\right)}$$

The gastrointestinal compartment accounts for the tissue water volume of the intestines and the stomach where alcohol is first absorbed. The stomach and intestines water volumes are grouped into one compartment because they are connected directly to the liver via the hepatic portal vein and because they are the sites of oral alcohol absorption. The blood flow rate in the hepatic portal vein is about 2/3 of the total blood flow rate v_L in the lever. Let C_{Cet} and C_{Get} denote the ethanol concentration in the central compartment and the gastrointestinal

compartment, respectively. Let V_G be the volume of distribution of the gastrointestinal compartment and let C_{S0} be the initial concentration of ethanol in the stomach. A mass balance on the gastrointestinal compartment gives the following differential equation:

$$V_G \cdot \frac{dC_{Get}}{dt} = \frac{2}{3} v_L \cdot \left(C_{Cet} - C_{Get}\right) + k_S \cdot V_S \cdot C_{S0}.$$

After entering the liver, ethanol is converted into acetaldehyde by the enzyme alcohol dehydrogenase (ADH) and cytochroom P450 (CYP). This substance is poisonous, but it is converted into acetate by enzyme aldehyde dehydrogenase (ALDH). These coupled chemical reactions, of which the first one in reversible and the second not, play an important role model of enzyme kinetics (see Fogler, 2005). The rate of disappearance r_{et} with which ethanol is eliminated is a function of the ethanol and acetaldehyde concentrations C_{et} and C_{ac} (other symbols are reactions constants), and it is given by the following formula:

$$-r_{et}(C_{et}, C_{ac}) = \frac{v_{\max_{ADH}} \cdot C_{et} - v_{\operatorname{rev}_{ADH}} \cdot C_{ac}}{k_{m_{ADH}} + C_{et} + k_{\operatorname{rev}_{ADH}} \cdot C_{ac}}.$$

The rate of disappearance r_{ac} of acetaldehyde elimination is given as a function of the concentration C_{ac} (other symbols are reactions constants) by

$$-r_{ac}(C_{ac}) = \frac{v_{\max_{ALDH}} \cdot C_{ac}}{k_{m_{ALDH}} + C_{ac}}$$

We will use both formulas in the modeling of alcohol metabolism in the liver. Let C_{Cac} and C_{Gac} be the acetaldehyde concentration in the central compartment and in the small intestine. The change of acetaldehyde concentration in the gastrointestinal tract is given by the equation

$$V_G \cdot \frac{dC_{Gac}}{dt} = \frac{2}{3} v_L \cdot \left(C_{Cac} - C_{Gac} \right).$$

The liver is modeled as a tubular flow reactor partitioned into N subcompartments that each contribute to alcohol clearance. Let the total volume of distribution in the lever be V_L and let the distribution volume for each part be ΔV_L (thus: $\Delta V_L = V_L / N$). Let C_{Letl} and C_{Lacl} be the ethanol and acetaldehyde concentration, respectively, in subcompartment 1 of the lever, and so on. We get the following equations:

Subcompartment 1:

$$\Delta V_L \cdot \frac{dC_{Let1}}{dt} = v_L \cdot \left(\frac{1}{3}C_{Cet} + \frac{2}{3} \cdot C_{Get} - C_{Let1}\right) + r_{et}\left(C_{Let1}, C_{Lac1}\right) \cdot \Delta V_L$$
$$\Delta V_L \cdot \frac{dC_{Lac1}}{dt} = v_L \cdot \left(\frac{1}{3}C_{Cac} + \frac{2}{3} \cdot C_{Gac} - C_{Lac1}\right) - r_{et}\left(C_{Let1}, C_{Lac1}\right) \cdot \Delta V_L + r_{ac}(C_{Lac1}) \cdot \Delta V_L$$

Subcompartment 2:

$$\Delta V_L \cdot \frac{dC_{Let2}}{dt} = v_L \cdot (C_{Let1} - C_{Let2}) + r_{et} (C_{Let2}, C_{Lac2}) \cdot \Delta V_L$$
$$\Delta V_L \cdot \frac{dC_{Lac2}}{dt} = v_L \cdot (C_{Lac1} - C_{Lac2}) - r_{et} (C_{Let2}, C_{Lac2}) \cdot \Delta V_L + r_{ac} (C_{Lac2}) \cdot \Delta V_L$$

Subcompartment N:

$$\Delta V_L \cdot \frac{dC_{Let(N)}}{dt} = v_L \cdot \left(C_{Let(N-1)} - C_{Let(N)}\right) + r_{et}\left(C_{Let(N)}, C_{Lac(N)}\right) \cdot \Delta V_L$$
$$\Delta V_L \cdot \frac{dC_{Lac(N)}}{dt} = v_L \cdot \left(C_{Lac(N-1)} - C_{Lac(N)}\right) - r_{et}\left(C_{Let(N-1)}, C_{Lac(N)}\right) \cdot \Delta V_L + r_{ac}\left(C_{Lac(N)}\right) \cdot \Delta V_L$$

Finally we describe the exchange of material between the central compartment and the muscle and fat compartment. Some notations: v_M is the blood flow rate to the muscle and fat compartment, V_C and V_M are the volume of distribution in the central compartment and in the muscle and fat compartment, respectively, and C_{Met} and C_{Mac} are the ethanol and acetaldehyde concentration in the muscle system, respectively. The following equations hold:

$$V_C \cdot \frac{dC_{Cet}}{dt} = -v_L \cdot \left(C_{Cet} - C_{Let(N)}\right) - v_M \cdot \left(C_{Cet} - C_{Met}\right)$$

$$V_{C} \cdot \frac{dC_{Cac}}{dt} = -v_{L} \cdot \left(C_{Cac} - C_{Lac(N)}\right) - v_{M} \cdot \left(C_{Cac} - C_{Mac}\right)$$
$$V_{M} \cdot \frac{dC_{Met}}{dt} = v_{M} \cdot \left(C_{Cet} - C_{Met}\right)$$
$$V_{M} \cdot \frac{dC_{Mac}}{dt} = v_{M} \cdot \left(C_{Cac} - C_{Mac}\right)$$

For the 'standard man' with weight of 69.4 kg you may choose the following parameter values (Umulus et al, 2005):

$$\begin{split} V_G &= 2.4(l), \ V_L = 1.1(l), \ V_C = 11.6(l), \ V_M = 25.8(l), \ v_L = 1.35(l/\text{min}), \ v_M = 0.75(l/\text{min}), \\ v_{\max_{ADH}} &= 101(\text{mg/min/[kg liver]}), \ k_{m_{ADH}} = 18.4(\text{mg/l}), \\ v_{\text{rev}_{ADH}} &= 32.6(\text{mmol/min/[kg liver]}), \ k_{\text{rev}_{ADH}} = 1, \\ v_{\max_{ALDH}} &= 124.5(\text{mg/min/[kg liver]}), \ k_{m_{ALDH}} = 0.055(\text{mg/l}). \end{split}$$

Graphical computer models of alcohol metabolism

All mathematical models that were described in the previous section can be converted into computer models. In general, the computer implementation of a mathematical model consists roughly of two phases: specification of the mathematical model and simulation of the model. Starting with the description of the first phase, Coach 6 has a graphical interface to describe a model qualitatively (see the screen shots in the examples below). In the graphical model you specify which quantities in the mathematical model play a role (distinguishing parameters and state variables), how they depend on each other, which formulas for quantities are used and which values parameters have. The graphical model is automatically translated into a system of equations that is used in a computer simulation, i.e., in running the model. We will look at some examples of alcohol clearance from the human body. We will assume that a 'standard glass' in the catering industry contains 10 grams of alcohol, regardless of the type of beverage. Parameter values are estimated on the basis of the reported literature values.

Widmark computer model

We start with the Widmark model, in which we work with the formulas of Seidl et al (2000) for the Widmark factor. Thus, after immediate consumption of n drinks holds:

$$\frac{d \text{ BAC}}{dt} = -\beta \cdot t, \quad \text{BAC}(0) = \frac{n \cdot D}{r \cdot W}, \quad r(\text{men}) = 0.3161 - 0.004821 \cdot W + 0.004632 \cdot H,$$

r(women) = 0.3122 - 0.006446 \cdot W + 0.004466 \cdot H.

The screen shot below (Fig. 7) shows the graphical model and a run for the average German man who has consumed two drinks. The graph illustrates that there is a weakness in the computer model: the computed BAC becomes negative after about two hours. In reality this is not possible of course. But having a critical look at the quality of a (computer) model is actually something that pupils have to learn or that has to become second nature.



Fig. 7. Screen shot of the simple Widmark computer model after two alcoholic drinks.

We can already make the Widmark computer model somewhat more realistic by choosing minutes as time unit instead of hours, and choosing BAC < 0 as stop condition. Furthermore, we will assume that not all drinks are consumed at once, but at regular intervals, say of 30 minutes. This means that we assume that every 30 minutes the blood alcohol concentration increases instantaneously with D / $(r \cdot W)$. In the screen shot below (Fig. 8) you see the graphical model, the graph of computed blood alcohol concentration against time, and a measured BAC curve of the author drinking eight glasses of red whine at regular time intervals. Ignoring the apparent overshoot of BAC shortly after each drink, the accordance between model and measurement is good for a clearance rate β of 0.0025 g/l/min. By the way, the alcohol consumption has been specified as a repeated pulse of height D / V_d every 'drink interval', but it could also have been specified by drawing a sketch of the drinking behavior or by implementing a repetition loop by means of 'events'. From the computed BAC curve you could draw the conclusion that BAC after consumption of two glasses has come above the legal limit of 0.2‰ for persons under age of 24. Another conclusion is that this particular person must wait more than seven hours after his final drink before the blood alcohol concentration is again below 0.2‰.





Wagner computer model

In the screen shot below (Fig. 9) we assume an alcohol consumption of drinking three glasses 'ad fundum' on an empty stomach: one at the start of the experiment, one after 40 minutes, and another drink 50 minutes later. In the computer model we have specified the 2^{nd} and 3^{rd} intake of alcohol by means of 'events' (represented graphically by an icon with a thunderbolt). Coach is a actually hybrid modeling environment for continuous-time and discrete-event dynamic modeling. With events one can take actions when a certain condition is met; see the yellow page in the screen shot for the event of consuming the third drink. The first alcoholic drink is just the initial condition (BAC(0) = BACincrease). Alternatively, the intake can be specified by means of mathematical formulas (e.g., with the Pulse function) or by drawing a sketch of the drinking behavior.

Fig. 9. Screen shot of the Wagner computer model for regular consumption of 3 standard units.



In the comparison of the computer model and the measured data we assume a time delay of half an hour for absorption of the consumed alcohol into the total body water: for this reason we have translated the graph of the measured BAC 30 minutes to the left. Alcohol clearance follows in the Wagner model Michaelis-Menten kinetics. The parameters $v_{max} = 170$ mg/min and $k_m = 45$ mg/l have been chosen such that a reasonable match between the measured data and the computer model exists, at least if one ignores overshoot of blood alcohol concentration. But obtaining good values for parameter appears to be quite tricky in practice: for instance, the values $v_{max} = 340$ mg/min and $k_m = 290$ mg/l are almost as good.

Norberg 2-compartment computer model

Comparing a mathematical model with real data is essential for judging the quality of a model. We use in this paper data collected by ourselves with a breath analyzer as well as data from research literature. We will use in our model of intake and clearance of alcohol data collected for subjects no. 19 and no. 22 in the clinical study described in the SWOV-report R-2001-19 (Mathijssen & Twisk, 2001). Subject no. 22 (female, 54 kg, 40 years, drinking daily) consumed, just like most of the participants, on two different days 72 grams of pure alcohol, in three equal portions of 24 gram. For each alcohol portion was available a drinking time of 25 minutes. A quarter of an hour later began measurements by means of breath analysis. Subject no. 19 (female, 66 kg, 20, drinking weekly) consumed only one portion of 24 grams of alcohol. Using the hybrid Widmark formula and using the formulas of Watson et al (1980) for the volume of distribution, the blood alcohol concentration could be predicted as

BAC =
$$\frac{D}{18.075 + 0.3186 \cdot G} - \beta \cdot (t - 0.5)$$
,

where *D* is the amount of alcohol consumed (in gram), β is the clearance rate (in g/l/h), and *t* is the amount of time (in hours) passed since alcohol consumption. The measured data and the predicted values for the two participants are listed in Table 2 below.

Table 2. BAC data of subjects no. 19 and no. 22 in the SWOV-report (Mathijssen & Twisk, 2001)

Development of BAC after consumption of 72 g pure alcohol by subject no. 22						
Time of measurement (after start, in minutes)	40	80	120	150	180	210
Amount of alcohol consumed	24	48	72	72	72	72
BAC measurement 1	0.55	0.97	1.45	1.38	1.27	1.10
BAC measurement 2	0.55	1.15	1.47	1.47	1.31	1.22
Predicted value (β =0.175)	0.52	1.09	1.65	1.56	1.48	1.39

Development of BAC after consumption of 24 g pure alcohol by subject no. 19					
Time of measurement (after start, in minutes)	40	70	100	130	
Amount of alcohol consumed	24	24	24	24	
BAC measurement	0.46	0.32	0.21	0.16	
Predicted value (β =0.2)	0.44	0.34	0.24	0.14	

The screen shot below (Fig. 10) illustrates that the Norberg 2-compartment model does not give a good match between measurements and model for subject 19, whereas the

hybrid Widmark model worked reasonably. In the computer model we have used a rate of intake of alcohol equal to 24/25 = 0.96 g/l/min for time between 0 and 25 minutes, and 0 elsewhere. Such a function can be specified in Coach by means of the Pulse function: Pulse(*t*;0;25;24/25). Thus, we obtain the following system of differential equations in the 2-compartment model:

$$\frac{dA_C}{dt} = \text{Pulse}(t;0;24;24/25) - CL \cdot C - CL_d \cdot C + CL_d \cdot C_T - CL_u \cdot C$$
$$\frac{dA_T}{dt} = CL_d \cdot C - CL_d \cdot C_T, \qquad \frac{dA_u}{dt} = CL_u \cdot C,$$

where A_C , A_T , and A_u , are the amounts of alcohol in the central compartment, in the peripheral compartment, and in the urine, respectively.

Fig. 10. Screen shot of the Norberg 2-compartment computer model with data of subject no.



A number of things catch the eye in the computed BAC curve: there exists a fast increase of BAC in the central compartment and after the peak value the alcohol concentration falls rapidly down under the values of the peripheral compartment. For some time there is a decline in alcohol concentration in both compartments that is almost linear. The amount of alcohol that leaves the body via urine is in the computer model about 1% of the total amount consumed. It cannot be denied that the match between measurements and computer model is



not good. The main reason for this is that we applied a mathematical model for intake of alcohol via intravenous infusion under completely different circumstances, viz., oral intake of alcohol. Of course the blood alcohol concentration raises rapidly when it is injected directly into the bloodstream. Our graphs are indeed consistent with graphs found in the scientific literature about clinical trials in which alcohol supplied by intravenous is infusion. The 2-compartment model is not really made for oral intake of alcohol. Such a critical look at circumstances under which experiments take place is something that we want to achieve with our pupils: a critical look at the applicability of methods should be second nature.

For a better match between the measurements and the Norberg 2-compartment model we must use a better model for the intake of alcohol. One solution is to use a smaller dose in the computation, as if just part of the alcohol consumption really matter. Figure 11 shows the computed graphs when we use an 'effective dose' of 18 grams of alcohol in 25 minutes. Then we achieve a nice match, but in an artificial way. More promising is it to use the Norberg 3-compartment model because in this model intravenous and oral intake have been separated.

Norberg 3-compartment computer model

In the Norberg 3-compartment model the so-called first-pass metabolism is taken into account: in the screen shot below (Fig. 12), which is a computer run for subject no. 19, you can see that the peak value of BAC in the central compartment is smaller than in the 2-compartment model. For the rest there is no great improvement in the match between experiment and computer model. With a suitable choice of 'effective oral dose', just like we did in the 2-compartment model, the conformity between experiment and model can be improved much. The volumes of distribution are theoretical volumes anyway. Henceforth we will use in the computer models the notation A_C , A_T , A_l , and A_u for the amount of alcohol in the central compartment, the peripheral compartment, the liver and the urine, respectively.

Fig. 12. Screen shot of the Norberg 3-compartment computer model with data of subject no. 19.



Fig. 13. Screen shot of the Norberg 3-compartment computer model with data of subject no. 19. and with improved modeling of intake of alcohol.



Another description of oral intake of alcohol leads to a better, but still not perfect match between experiment and model: a delayed absorption following fist-order kinetics, like we have described before in the hybrid Widmark model. This means that we assume:

rate of intake =
$$\begin{cases} 0 & \text{if } t < t_0 \\ D \cdot k_a \cdot e^{-k_a \cdot (t-t_0)} & \text{if } t \ge t_0 \end{cases}$$

where *D* is the alcohol dose, k_a is the absorption coefficient, and t_0 is the time of delay. The screen shot above (Fig. 13) shows that the alcohol concentrations in the liver and the central compartment take less extreme values than before and that a good result can be obtained for suitable choices of parameter values. By the way, we have divided the intake of alcohol during consumption time into four equal parts in order to get a more realistic consumption pattern (here we use again the Pulse function). We have not included the intake via intravenous infusion anymore because the dose will be taken zero in all examples.

For a more adequate model we need a mathematical model that uses more organs. In the Pieters 3-compartment model and in the physiologically based 5-compartment model of Umulis et al this is the case. But before we do this, also have a look at the nice result shown in figure 14, in which measurement 1 of subject no. 22 is compared for suitable parameter vales with the result obtained with the Norberg 3-compartment model.

Fig. 14. Screen shot of the Norberg 3-compartment computer model with data of subject no. 22.

 00 Ն 🖸 🗖 🖇 🖓 🚺 2.8 r 4 C (g/l) Ct (g/l) Au (a) 3.6 2.6 3.4 3.2 ent 1 (g/ 2.4 3.0 2.2 2.8 2.0 2.6 2.4 1.8 2.2 2.0 1.6 1.4 1.8 1.2 1.6 1.4 1.0 1.2 0.8 1.0 0.6 0.8 0.6 0.4 Au (g) 0.4 0.2 0.2 t (min) 500 600 900 k m (mg/l Onlosser: BK4

Pieters 3-compartment computer model

Figure 15 shows a graphical implementation of the Pieters model that compares well for suitable parameter values with the measurement of subject 19.



Fig. 15. Screen shot of the Pieters 3-compartment computer model with data of subject no. 19.

For the initial concentration in the first compartment (the stomach) we have chosen the alcohol concentration that would hold in the human body in case the alcohol had been able to distribute immediately over the total body water in an estimated volume of distribution V.

Disadvantage of the data set in the previous example is that so small. In Figure 16 we present the measured data of the author drinking 3 glasses of red whine at once on an empty stomach early in the morning. The Pieters model matches for suitable parameter values the recorded blood alcohol concentration very well. In the computer model we have chosen for the feedback parameter a negative value ($a = -0.6 \ l^2/g^2$) to get an accelerated intake of alcohol because drinking happened after fasting. Other parameter values have also been chosen within ranges reported in the literature for the Pieters model.

Fig. 16. Screen shot of the Pieters 3-compartment computer model after drinking 3 standard units.



A physiologically based 5-compartment computer model

Most detailed is the physiologically based 5-compartment model of Umulis et al (2005). This model is typically not implemented by pupils themselves, but it serves as an example for them of how modeling is done in modern pharmacokinetic research (Rowland et al, 2004).

Fig. 17. Screen shot of the Umulis 5-compartment computer model.



Figure 17 illustrates the complexity of the model. In our implementation of the liver as a tubular flow reactor we have divided the organ into five subcompartments. Not all relation arrows between parameters and other variables have been drawn in the graphical model for the sake of clarity of the picture. The dotted lines in the graphical model indicate that we would like to see the liver as one unit and that the details can be taken out of sight of the user of the computer model; Figure 18 show this looks like. Using this presentation of the computer model teacher and pupils can discuss the model more easily. The match between model and data measured for subject no. 19 is good. However, since we are dealing with a stiff system of differential equations, the time step in the ODE solver must be chosen very small (0.001 min) to avoid numerical problems. This means that the computation takes long.

Fig. 18. Screen shot of the Umulis 5-compartment computer model with data of subject no. 19.



For those who still have doubts about the usefulness of the physiologically based model we give Figure 19 that is a screen shot of the graphs of alcohol concentration in the small intestine and the central compartment of a sober person with a personal weight of 80 kg after consumption of 24 grams of alcohol in 20 minutes. The background graph belongs to measured data from a clinical trial (Di Padova et al, 1987). It is easy to see that it takes about is two hours after consumption of this amount of alcohol before the concentrations in the two compartments are equal. At that moment, most of the consumed alcohol has been taken into the total body water.



In the computer model of Figure 19 we have chosen for the feedback parameter a negative value (a = -0.0003) to get an accelerated intake of alcohol because the subject in the clinical trial had fasted before the experiment. Choosing a positive value can simulate the effect of a meal. Figure 20 has been obtained by choosing a equal to +0.0003. It is evident that the peak value of BAC for alcohol consumption with a full stomach is less high than with an empty stomach. The effect is after some time gone.

Conclusion

The last example in the previous section illustrates in particular the power of mathematical modeling: After one has successfully constructed a mathematical model and a corresponding computer model that describe reality adequately for well-chosen parameter values, one can investigate the influence of various factors in the model by varying the parameter values. We have already seen that the physiologically based 5-compartment model predicts that someone gets drunk faster if he or she consumes alcohol with an empty stomach than a person who drinks after or during a meal. With this computer model, but also with the less complicated models described in this paper, a pupil can investigate whether a person who drinks 3 glasses of beer at once may drive a car earlier than a person who consumes the same amount of alcohol, but at a slower speed and with time intervals in between. A pupil can also find clues that explain why women in general get drunk earlier than men when they consume the same amount of alcohol. A pupil could investigate what happens when drugs inhibit the conversion of acetaldehyde into acetate. Anyway, the amount of acetaldehyde would accumulate under these circumstances. This chemical substance has physiological side effects like sickness, decrease of blood pressure, flushing, and qualms. These aversive sensations in people are actually used in treatments of alcoholics.

The diversity of the models of alcohol intake and clearance in humans that have been discussed in this paper give a good idea of the common method of working in mathematical modeling: first one simplifies the situation to such an extent that a simple (computer) model can be constructed. Hereafter one evaluates this model, preferably by comparing it with experimental data, and one adapts the model if necessary. In the process of evaluation, parameter estimation plays an important role as well. The complexity of finding suitable parameter values must not be underestimated. Adaptation of the model normally means that one makes the model more complicated by taking more factors that cannot really be neglected into account or by undoing some earlier simplifications. In this way one comes into the process of simplifying first and then adding step-by-step more details to the model, with the purpose of matching the model better with reality.

This progressive aspect of graphical modeling is also a pointer to a suitable manner to introduce it to pupils: it seems best not to let them construct out of the blue some well-functioning model, but to let them first improve an existing model by changing or adding details. Here it is important that pupils can compare the results of the computer model with real data, preferably collected in an earlier measurement activity. For the modeling of alcohol

intake and clearance breath analysis equipment of sufficient quality is available for the price of 125 euro; professional equipment, which researchers use in clinical trials and which the police uses for traffic control is more expensive (about 700 euros), but it can be rented and sometimes borrowed. A third alternative is to build yourself analysis equipment by means of a rather cheap gas sensor (about 20 euros). Anyway, measurement of intake and clearance of alcohol in humans are feasible as practical work for pupils at school. Confrontation of a model with reality turns graphical modeling not only into a fun way of learning, but it also makes it exciting, challenging, and concrete work for pupils. Experience is that this is practicable (TdB, 2003) and that pupils can actually use the same theoretical framework, methods and techniques as practicing professionals.

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The Nature Of Scientific Models In Physics - A Philosophical Perspective

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Abstract

Although scientific models are mentioned and used all the time in physics education, there is very little reflection on what these models really are, and how they relate to reality. For instance, our formal concept of the electron is taught as if it is really as mundane as a grain of sand, while it is in reality a summation of deductions from experimental observations. Furthermore, there is often inconsistency in the terminology, with the terms 'model' and 'theory' used as synonyms by many authors for the same body of knowledge, e.g. 'Bohr's atom model' and 'Bohr's theory of the atom'. This presentation is an attempt at a fundamental philosophical analysis of scientific models in physics and its implications for science education.

Motivation

A few years ago a student asked me exactly what the difference between a model and a theory is. To my surprise, I couldn't give an answer that was satisfactory to myself. When I started to consult literature, I found that very little is actually written about this, and some of what is written is inconsistent. For example, some textbooks refer to Bohr's model of the atom, others to his theory. It is assumed that the terms are so common and familiar that they are rarely even included in textbooks' indices of terms. But is it really obvious and common knowledge?

The question "What is a scientific model" can be approached from two perspectives: The pragmatic (what are models used for?), and the ontological (what is the inherent nature of models?). The following analysis is primarily ontological, with relevant pragmatic aspects also noted. We must first know what a scientific model and theory is before we can state what the difference between them is.

Another comment bears making: As physicists, we use mathematics as our ideal for science. We insist on clear, precise and unambiguous definitions of terminology. This makes it even stranger that we do not really have a consensus on the meaning of such basic epistemological terms as model, theory, law and principle. On the other hand, such exact definition could be limiting. Stafleu (2001) argued that the positivist demand for exact definitions is often unnecessary and too restrictive. It can be more productive to work with a good characterization, which leaves room for extension of a concept, e.g. when new knowledge become available. Over time, the meanings of words change through a process of extending their usage. Words also acquire different meanings to people using them in different contexts in their working environments.

Literature survey

It is by no means obvious and common knowledge what "model" means in the context of science. A variety of appropriate sources to the study, *viz*. dictionaries in various languages, textbooks on philosophy of science and introductory physics textbooks (1st year tertiary level) were consulted.

The dictionaries did not help much. For example, the Oxford English Dictionary (Oxford, 1978) has more than a page of examples of uses of the word. However there is no description of the use of the word in the scientific sense of an abstract conceptual representation, except for the following interesting example:

c. A description of structure. Obs.

1578 T. Digges in L. Digges *Progn. Everlasting* To Rdr. M, I founde a description or Modill of the world and situation of Spheres Coelestial and Elementare according to the doctrine of Ptolome. *Ibid.*, But in this our age one rare witte.. hath by long studie,..deliured a new Theoricke, or model of the world, shewing that the earth resteth not in the Center of the whole world, but only in the Center of thys our mortal world.

The usage of the word in common English, as described in the dictionaries, does not really include the way it is normally used in the context of the physical sciences. The meanings given for the word fall into four broad classes:

> A physical representation of something else;

- ➤ a new type (e.g. a model of car);
- ➤ a role model to be followed; and
- ➤ a person modelling clothing.

In science the first sense is the only one used, but the use is not limited to a physical representation. It has been stretched by usage to that of an abstract representation. A first distinction should thus be made between the general uses and the scientific use of the word.

In order to find authoritative references for the latter, some readily available books on the philosophy of science were consulted (Kemeny, 1959; Stoker, 1969; Beerling *et al.*, 1975 and Geertsema *et al.*, 1997). Surprisingly, none of them contained even a brief note on it, much less a discussion on its meaning(s) in the scientific context and language. They all simply use the word, implying that the meaning is understood. Two books by Bertels and Nauta (1970, 1974) had models as their sole subject. The second book also contains a list of definitions or descriptions from sixteen other authors. According to them, a model can be defined as follows:

There exists a system B There exists a system O B is independent of O If B provides information about O by analogy Then B is a model of O

Beerling *et al.* (1975) make a distinction between *deductive theories* and *deductive-hypothetical models*. A deductive theory is a formal logical construction (of theorems), based on symbols, axioms and postulates. A typical example is the postulates and theorems of abstract algebra. The process of theory construction must be entirely independent of physical meaning – it depends only on logic. A deductive-hypothetical model on the other hand, is the 'normal' scientific theory of a phenomenon.

Most textbooks consulted did not even have the term model in the indices - at most they had an entry for Bohr's model of the atom. Only one book (Knight, 2004) had a three quarter page discussion as part of the introduction. He writes "A model is a simplified description of reality – much as a model airplane is a simplified version of a real airplane – that is used to reduce the complexity of a problem to the point where it can be analyzed and understood."

And also:

"Learning how to simplify a situation is the essence of successful modeling."

In his book on the history of science Gribbin (2002) states that "Models are important, and helpful; but they are not the truth; in so far as there is scientific truth, it resides in the equations."

Science teachers at all levels (primary to tertiary) make use of models to teach. This has led to research about the educational aspects related to models. Smit (1995) compiled the following list of the general views held by the scientific community on the nature and functions of models in physics from a literature survey:

- Models are constructions of the human mind and are temporary by nature.
- > The models used in physics are not pictures of the underlying reality but are viewed as representations of real entities.
- An important role is played by models in the acquisition of knowledge about nature and the comprehension of nature.
- A clear distinction is made between a model and a physical theory. Ideally, a theory should contain the description of a plausible model, modelled on some thing, material or process that is already well understood.
- Models help the physicist to predict, describe and explain natural phenomena, particles and structures. The descriptions are never complete. They simplify phenomena or make them easier to deal with. Different models can be used to describe the same entity.

Kuipers (1969) as quoted by Smit (1992) also distinguishes between two broad classes of models in science and technology, based on their purpose, being *knowledge* models and *manufacture* models. *Knowledge* models are the scientists' models – they supply knowledge of reality. Their primary function is to provide a better understanding of nature. Secondary functions are description, prediction and explanation of natural objects, processes or phenomena. *Manufacture* models are the engineers' models, which help them to manufacture real appliances. The models are used to experiment on and serve as plans for construction.

Du Toit (2000) discusses models for engineering applications and distinguishes between four levels of modelling used in numerical modelling of physical processes and configurations. This discussion demonstrates an advanced development of the term, implying not only familiarity, but also general acceptance and usage.

From the sources, the purpose of a scientific-technological model can be summarized as being to:

- > imitate, demonstrate, illustrate or simulate; or
- ▶ highlight, i.e. emphasise or concentrate (focus on a particular aspect).

Models and reality

From the beginning of systematic philosophy a key question was what really exists, what really *is*, *i.e.* the ontological question. This leads directly to the question of if and how we can know this existing reality, *i.e.* the epistemological question. Since Descartes made his famous statement: *"Cogito, ergo sum"*, it has been generally accepted that the world/nature/universe does exist, but that it is neither completely known, nor completely knowable. The questions of ontology and epistemology have occupied great minds for millennia and we shall not presume to speak the final words here. Nevertheless, they are fundamental to the process of doing, learning and teaching science. Despite this, scrutiny of Physics handbooks shows that they are mentioned only very rarely, although answers to them are assumed implicitly. A prominent example is the concept of models as used in Physics.

Do we believe our scientific models and theories to be statements of reality (truth), or are they merely intellectual constructs with which to analyse nature? During the last two centuries two opposite views of science (and therefore also of the tools of science, like models) have developed, viz. determinism and instrumentalism. The deterministic view is that we learn to know reality (i.e. "the world") in science through a process similar to Soduko. The universe/nature exists, it gives us some clues about itself. Through science we unravel the mystery, getting to know it better and more completely all the time. In this view science consists of a body of facts. For the early modernists and rationalists like Descartes and Newton, these fact were true; they were considered as descriptions of actual reality.

The development of modern physics in the twentieth century caused the second view, called instrumentalism to become predominant. Instrumentalists refer to Popper's view that the logical positivists' idea of the verification of theories is unattainable. Theories cannot be verified, only falsified, because we do not know the absolute truth against which it can be verified. However, we can falsify a theory by demonstrating its failure in one single aspect of what we do know of reality. Science can be reliable, but not true. Furthermore, scientific disciplines are practised within paradigms, which can and do change as science itself develops (Kuhn, 1973). All scientific knowledge is preliminary in nature and models and theories are only instruments i.e. useful tools used to study reality with no inherent truth. They do not make statements about reality.

Ontological view

The underlying ontological view that forms the basis for a characterisation of scientifictechnological models is stated as follows:

- There is a reality, a universe with all its objects and processes that exists and which we are studying.
- We do not and cannot know this reality in its totality.
- In order to study, understand and describe it, we make use of models. These models are therefore representations of aspects of reality. As such they do not describe the whole of that reality, but merely the part that we now know and understand in terms of the model itself.

The model is thus a cognisant reflection of reality. This is not the same as the instrumentalist approach, i.e. it does not consider the models to be devoid of all inherent reality (*i.e.* truth) and merely as useful tools. It does accept that the models are approximations of reality within the context of cognisance, albeit limited in both content and scope.

Characterisation of a scientific model

On the basis of the analysis given, a scientific model (hereafter referred to as a model for brevity) is characterised as follows:

A scientific model is a simplified and limited representation of reality, used to obtain understanding and formalise theoretical knowledge.

It must be noted that this characterisation does not claim to be either inclusive of everything that could be considered as a scientific model, nor exclusive of everything that cannot. It is based on the assumption that the reader has a concept of the meaning of the term, due to experience and

education. It is intended to be useful as educational terminology and as a guideline for epistemological analysis.

Functions of scientific models

By stating that a model could be a physical as well as a conceptual representation of an object or a process, the meaning of the word in the scientific context has already been extended from that given in the dictionaries. A conceptual representation can be an intellectual construction, such as a mathematical formulation, or a computer programme that provides an animation. Representing a process rather than an object is also an extension of the common usage, but is general practice in natural science.

A model can also be a representation of a concept. A good example is the representation of force. Newton conceived it as something that can cause action at a distance. Faraday thought in terms of field lines. In modern physics it is described in terms of an exchange of carrier particles. In all three cases we are dealing neither with material objects, nor with physical processes, but with intellectual creations introduced in scientific theory. These concepts have become so familiar that we have come to believe in their physical existence, while they find their validity basically in the models of them used in science.

Classification and hierarchy of models

A classification of types of models as used in science and technology can be posed. One benefit of this classification is that it gives a transition from the concrete (demonstrative physical scale models) to the abstract (illustrative, conceptual, theoretical). Thus there is a hierarchy of abstraction in the representation:

- Physical, static (typically scale) model
- Physical, dynamic model
- CAD-type or wire frame drawing
- Animated computer demonstration
- Conceptual (analogy) model (e.g. comparison of the atom with the solar system)
- > A descriptive set of mathematical equations
- A scientific-mathematical law (e.g. Newton's universal law of gravity)
- ➤ A scientific theory.

Models and theories

Do the last two classes given in the previous paragraph really constitute models? The development from classical mechanics to general relativity has given us two alternative ways in which to view or comprehend gravity; the future may provide even more. In the sense that these theoretical constructions are representations of reality, they are actually formalised conceptual models, albeit very advanced or developed ones. Like other models, they provide us with an insight or demonstration of some important aspects of that part of reality they show us, but not everything about it. For example, Newton's universal law of gravity provides us with

- the concept of an attractive gravitational force;
- an algorithm to calculate the gravitational attraction between two bodies with mass, separated by a distance; and
- an analogy to apply to the electrostatic force between two charged particles, separated by a distance (for which it becomes a model itself).

It also leads us to some fundamental questions, but does not provide any answer to them, e.g.

- What is the nature and cause of the attractive force?
- ➤ Does the force exist, even if there is only one body with mass?

The question of whether a theory is a type of model is one of interpretation. The difference is one of degree and lies in tradition, not semantics. To distinguish between them is not incorrect, but such a distinction is inherently fuzzy. In my opinion it is epistemologically more useful to distinguish theories as a class of model, rather than wholly separate entities.

Models and realism: deterministic versus realistic models

There is another epistemological issue: are the laws of science deterministic and are the models based on them deterministic? This means that the model should, at least in principle, predict or describe exactly what is occurring in the physical object or process. Any deviation from reality by a deterministic model must only be ascribable to errors caused by simplifications in the model, to accuracy of measurement or to rounding errors in calculation. These deviations are intrinsic to the whole process of modelling. Consider for example a type of model that is being use increasingly in scientific research, *viz.* numerical models for computer simulations.

A typical numerical simulation consists of a combination of other models. Firstly, there are the theories of the physics involved in the problem. Secondly, there is the mathematical formulation of the problem. Thirdly, there is the discretization of the mathematical formulation in order to use an iterative algorithm to solve it on a computer. Lastly, there is the representation of the results of the model. The mathematical formulation of the model is in itself hierarchical and contains various levels of simplification and abstraction (Du Toit, 2000). All of these submodels can be sources of inaccuracy due to conceptual errors, numerical rounding or inappropriate scaling. The modeller must optimise between two conflicting requirements. In the first place, the numerical discretization must be fine and detailed enough to give sufficient resolution, both to obtain accurate solutions and to get a good representation. On the other hand, the finer and more detailed the discretization, the greater the computational load, which rapidly becomes too much.

It is not possible to have a deterministic numerical model. This is due to more than simplification and rounding error. It is also inherent to the physics on which a model is based. Not only does quantum and statistical physics preclude this on the microscopic scale, some very common and simple large-scale phenomena have been shown to display extreme dependence on initial conditions and non-linear behaviour in dynamics. Examples are the Duffing oscillator and turbulence in the convective flow of super-cooled helium (Addison, 1997). The study of these phenomena has popularly become known as chaos theory (more formally called non-linear dynamics). This makes it impossible not only in practice, but also in principle, to make exact deterministic calculations that demonstrate exactly and precisely what happens in reality.

Being prevented from constructing deterministic models by the realities of chaos, simplification and numerical rounding, we can still aspire to *realistic* models as a goal. These are models which, although not deterministic, mimic nature in such a way that the behaviour of the models cannot be distinguished from that of the physical systems they are representing. Such models can therefore be used to investigate the characteristics and behaviour of these physical systems, including the effects of changes in or to them.

Limitations of models

The first limitation of any model lies in the fact that it is a representation of reality. Reality itself is incompletely known at present, and probably not completely knowable in principle. This is why scientists use models – to enable conceptualisation of the unknown or unfamiliar. It follows that a model is intrinsically limited in its representation of reality.

The second limitation is that practice limits us in the detail that can be included in any model. We are constrained by a variety of factors from constructing a model in too fine detail. A model is therefore practically limited in its representation.

Thirdly, because we use models to enable us to conceptualise something, we cannot make the model so detailed as to become incomprehensible. This comprises a cognitive or intellectual limit.

Lastly, models are of temporary nature. With time, our insights change, or our designs do, or we change the models in the process of experimentation and development (Smit, 1995).

Conclusions

The general assumption that learners, and even all scientists, know what models are, is not valid. There is no explicit or even implicit consensus. It is imperative that a proper epistemological debate be conducted on this issue, as well as on the meaning of other related terms. It is also necessary that textbooks and educators should explicitly teach learners about it.

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Models and Simulations as tools in physics learning

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Abstract

We discuss some simple models using Modellus that have been useful in various university courses, spanning from an initial propedeutic course to experimental physics and a simulation laboratory. The different role of models is shown at those various levels of knowledge and expertise. Examples of application of Modellus in more difficult problems, such as the initial value problem giving rise to river meanders and the analogous boundary value problem for the flexural deformation of a long bar, are included.

Introduction

Many freshmen students have defective knowledge and understanding of basic concepts in science and poor mathematics skills. However, most of them are highly motivated and even skilled at using computers and their interest in computer applications can be used to improve their fitness and chances to succeed in their studies, thus helping us to reduce the failure and desertion rates of Science and Engineering freshmen. This paper addresses the use of models and simulations using Modellus, by Duarte et. al., in three settings: 1) a propedeutic course offered before their actual first trimester enrollment, to improve their communication and problem solving skills; 2) our experimental method courses at the second and third trimester where simulations are used as tools to support teaching and promote a better understanding of the model and the data analysis; and 3) a simulation laboratory course at the third trimester, to introduce students to models, their similarities and range of applicability to problems in different fields, including the simulation of meanders and elastic curves. The simulation files are available upon request. In the last part we give conclusions based on our experience.

Simulations supporting problem comprehension and formulation

Lack of comprehension of a problem by students prevents them from successfully translating it into mathematical terms, as a previous step to writing the right equations to solve, and thus reach its answer. The examples in this section exhibit some concrete obstacles impeding the student's progress to the solution and show instances of how simulations, using just the evaluation and graphing capabilities of Modellus, lend themselves to gradually advance their understanding of concepts and problems as well as of the solution methodology.

Problems giving raise to linear equations or relations

The type is well exemplified by the following two problems, taken from Perelman (1970), the first from kinematics:

«As I walked on the sidewalk beside the tram track, I noticed that every 12 minutes a tram passed me, while every 4 minutes a tram went in the opposite direction. How often do trams leave, assumed to be the same, from the terminal station at each end?»

Since no values of the tram and walking speeds are given, most students assume that these are unnecessary for its solution and their attempt to solve the problem fails. Assuming that these speeds are known and constant, one can write the expression for time between two successive trams going either way and work out the algebraic solution, which yields that this *lapse T* is the harmonic mean of the passing to crossing times *independently* of the speeds and further, that *any pair* of speeds with the ratio of (tram speed : walking speed) = 2:1 is associated with any pair of successive passing to crossing times in the ratio 3:1. The simulation just applies constant rectilinear motion and shows that the position of the successive trams going each way plotted as a function of *t* are two pairs of parallel lines, that the walker requires different times to intersect, according to their direction of motion. The triangles with horizontal and

vertical sides determined by the intersections of the line representing the walker's position with the parallels offer a shortcut to the solution. Figure 1 shows a set of speeds giving a crossing time of 4 minutes and a passing time of 12 minutes, as given in the quoted problem statement.



Figure 1. Passing and crossing of a walker by successive trams leaving the terminal stations

The second problem deals with mixing solutions with a different concentration:

6.0

3.0 4.0

5.0

مىلىمى 7.0

«Determine the amount of two solutions, one of 3% concentration and the other of 30% concentration, necessary to obtain a 12% solution.»

8.0 9.0

10.0 11.0 12.0 13.0 14.0

Here, the amounts of the given and of the desired solutions are not stated. To solve, mass and volume conservation is required. This problem let us recognize that some students do not understand the concept of *concentration*, and they required the instructor's help just to recall and understand the defining relationship between solute volume, solution volume and concentration, and the availability of the interactive simulation to show their relation was a great teaching and learning support, allowing the instructor to apply various strategies and stages to control the solution properties.

Models in the physics laboratory

1750.0 1500.0 1250.0 1000.0 750.0 500.0 250.0

.1.0

1.0

Our initial experimental laboratories are highly biased towards developing skills and knowledge in metrology and data handling, while keeping most lab activities based on using very simple measuring instruments. Video cameras and electronic sensors are available and used in some classes and computer simulations, allowing the idealized problem to be studied in detail, guide in planning and conducting the experiment, as well as in clarifying the data analysis.

Bouncing ball

The common occurrence of a ball bouncing off the floor is a very attractive phenomenon to study. The simulation helps to recognize that controlled conditions are required to obtain sensible answers, e.g., the value of the inelastic coefficient r, the ratio of velocity after to that before the contact. It also assists students to grasp why the (t, y) graph for balls dropped with any horizontal velocity is always a set of parabolic arcs and its difference from a stroboscopic picture. The simulation considers different values of the inelastic coefficient in the various cases, while keeping, for simplicity, all the other quantities the same allows students to be asked to recover the value of r from the slope in a log (height) vs. bounce number graph.

Lucas-Washburn law

This law addresses the absorption of water by paper and the advancement of the wetting front, which is easily performed experimentally (Fanelli et. al., 1990). The model considers nearly

perfect force balance between the wetting force, assumed constant, and a resistive force proportional to position and speed of progression of the wet front, which is easily integrated by separation of variables to yield a power law, namely, x proportional to the square root of t. Numerical solution is here for the equation dt(x)/dx but not for dx(t)/dt, because the initial condition x=0 at t=0 gives an indeterminacy for the latter. The simulation here offers students the opportunity to understand the effect in the x(t) and in the log-log plots of a small systematic error due to the fact that the initially measured x deviates from the assumed condition.

Models in the Simulation Laboratory

Since 1999, at our Science and Engineering Division we have taught the Simulation Laboratory course as a compulsory subject. Important features of this course are a) attempt to develop students' ability to understand and apply models, and b) to acquaint with symbolic mathematics computer tools. Since many of the examples considered in the course yield quite easily to numerical solution, we have found that using the purely numerical application Modellus is fruitful, enlightening and simpler for students to work with. Examples of the simulation creating an environment in which students can measure and invites comparison with results from the real world experiment, follow.

Pendulum with an arbitrary amplitude of oscillation

The simulation affords a simple way to study outside a physics laboratory the dependence of the period of a (frictionless) pendulum with amplitude of oscillation and gives some training for conducting the experiment because the procedure is the same, namely, to measure the time required for N complete oscillations.

This and the following simulation were provided originally by Ribeiro and Veit (2000), and a graph with phase-space trajectories was added in order to introduce students to this concept and type of representation.

Analysis of the amplitude of a forced oscillator near resonance

Resonance of mechanical, acoustical and electrical oscillators is a very important model, although quite difficult for freshmen to grasp theoretically and to work with experimentally, beyond a qualitative demonstration. In the simulation, the very important effect of a static force and the steady state amplitude of oscillation at different frequencies of the external force are determined in order to graph points of the resonance curve. Easy and quick comparison between the various cases with different frequency is very useful, for which the phase space graph allows a different perspective.

River meanders and bending of an elastic bar

River meanders are the loops formed by the riverbed as it flows downstream. Meanders can be described as curves whose tangent line makes an angle with the river mean axis that is proportional to the sine of the river length (Leopold and Langbein, 1966). The equilibrium shape of an elastic bar under an applied bending moment gives rise to a similar second order differential equation (Feynman et al., 1964). Both equations are similar to the equation of motion of a frictionless pendulum for arbitrary amplitude of oscillation, except that bending is a boundary value problem. However, we have used the initial value problem solver built in Modellus to show most of the interesting features of both systems (some of which may be studied following the guidelines to explore, describe and answer in the *Notes* window of meander.mdl) and, by trial and error parameter adjustment, we obtained very good approximations to the shape of bars with zero deflections at both ends.

Other examples

The logistic model of population dynamics due to Verhulst turns out to be quite realistic with respect to the slowing down of population growth, the attainment of a steady or equilibrium population and the decrease from an initial overpopulation condition. Comparisons with national or world census data for, e.g., the 20th century is quite reasonable and differences allow for conjectures about the effect of health care and wars to be made. Other simulations that have been found helpful in supporting or developing students' understanding are the

superposition of harmonic oscillations giving rise to beats and the numerical solution of ordinary differential equations describing coupled chemical reactions.

Conclusion

Use of simulations helps to pursue deeper and wider understanding of physical phenomena, models and concepts in students, and are a valuable diagnostic tool to test their understanding and preconceptions. Simulations also improve and develop enquiring, observing, experimental and analysis skills and empower the students to conduct and perform better experimental activities. Premade simulations may be very useful to help the less gifted students to better understand problems and to build those skills. In addition, promotion of collaborative and teamwork in class allows the more gifted students to be willing to help their peers.

Simulations are more profitable if flexible didactic strategies are set forth and we are able to identify the class' and individual's needs and respond accordingly. The ability to repeat them as often as needed lends great help to understanding and correcting misconceptions. Resorting and relying in the presentation of simulations should become a wider and more often used practice, even more so in theoretical and experimental classes.

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Brownian Motion in Viscous Liquids; Model and Numerical Simulation

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Abstract

We propose a model of Brownian motion of sphere particles in viscous liquids. The model can be solved analytically and simulated numerically. The analytic solution leads to the known diffusion law $\langle r^2 \rangle = Dt$ where the diffusion constant *D* is expressed by the radius and the mass of particles, the viscosity of liquid and the average time between consecutive collisions of the observed particle with molecules in liquid. The latter allows to make a simulation of the Perrin experiment and verify how the number of observed particles and the length of observation time influences the expected theoretical results. With the help of the analytic solution and presented numerical simulation we argue that the statistics usually used in real experiments is too small to achieve reasonable results being in agreement with the diffusion theory. To avoid the problem of the small statistics causing departures from the diffusion law we introduce the idea of so called Artificially Increased Statistics (AIS) and prove that with this method of analysing experimental data one can confirm the diffusion law even following trajectories of just few particles immersed in the liquid.

I. Introduction

Recently a big progress has been made in application of digital techniques in experimental physics what allows even students to perform milestone physics experiments at their own university laboratories. A good example is the Perrin experiment [1] – the first one that directly proved the atomic structure of matter. This experiment can be verified in student laboratory [2, 3, 4], however in some approaches [2, 4] it is difficult to confirm the linear dependence between the average squared displacement $< r^2 >$ of the particle in media and the observation time *t* as required by the Einstein – Smoluchowski diffusion law [5].

It is essential therefore to examine the minimal statistics (number of particles) one should consider in the limited observation time to reveal the major features of the diffusion law.

We propose an analytic Brownian motion model which can also be easy simulated numerically. The aim of this model is to investigate how the results of $\langle r^2 \rangle$ versus *t* depend on the number of observed particles and observation time. This study should help to set up the experiment properly and correctly analyse obtained results.

II. Description of the Model

Let the trajectory of a given mezoscopic particle of mass *m* in 2-dimensional space is $x^{\alpha}(t)$, where $\alpha = 1, 2$. We assume $x^{\alpha}(t)$ to be the discrete 2- dimensional time series with constant spacing τ in time, i.e.: $t = 0, \tau, 2\tau, ..., N\tau$.

The obvious notation $x^{\alpha}(i\tau) = x^{\alpha}_{i}$, $i \in N$ and $\Delta x^{\alpha}_{i} = x^{\alpha}_{i+1} - x^{\alpha}_{i}$ will be applied, where Δx^{α}_{i} is the instantaneous displacement of particle at $t = i\tau$.

The physical meaning of τ is the average time between consecutive collisions of the mezoscopic particle with other molecules in media. We assume that motion is stationary with no drift $\langle \Delta x^{\alpha} \rangle_n = 0$, and no correlations between different displacements. Hence:

$$\langle \Delta x_{i}^{\alpha} \cdot \Delta x_{j}^{\alpha} \rangle_{n} = \delta_{ij} \sigma^{2}$$
 (1)
where $\langle \cdot \rangle$ is the average taken over the ensemble of *n* mezoscopic particles.

The total mean squared displacement $\langle \Delta r^2 \rangle_n$ of the particles from their initial positions after N collisions can be easy calculated with the help of (1):

$$\left\langle \Delta r^2 \right\rangle_n = \left\langle \sum_{\alpha=1}^2 \left(\sum_{i=1}^N \Delta x_i^\alpha \right)^2 \right\rangle_n = \sum_{\alpha=1}^2 \sum_{i,j=1}^N \left\langle \Delta x_i^\alpha \Delta x_j^\alpha \right\rangle = \frac{2\sigma^2}{\tau} t$$
(2)

In order to calculate σ^2 let us notice that

$$\Delta x^{\alpha}_{i} = \tau < v^{\alpha}_{i} >_{\tau}$$
(3)

where $\langle v_i^{\alpha} \rangle_{\tau}$ is the time average velocity of the particle between *i* and *i* + 1 collisions. Hence, from eqs.(2) and (3):

$$\sigma^{2} = \tau^{2} \left\langle \left\langle \nu_{i}^{\alpha} \right\rangle_{\tau}^{2} \right\rangle_{n} \tag{4}$$

From the principle of equipartition of energy:

$$\frac{1}{2}m\left\langle\left\langle \nu_{i}^{\alpha}\right\rangle _{\tau}^{2}\right\rangle _{n}=\frac{1}{2}kT,$$
(5)

where T is absolute temperature and k is the Boltzmann constant. Therefore eq. (2) reads

$$\left\langle \Delta r^2 \right\rangle_n = \left(\frac{2kT}{m}\tau\right) t \tag{6}$$

The formula above is the standard diffusion law with the diffusion constant

$$D = \frac{2kT}{m}\tau\tag{7}$$

expressed in terms of τ .

Usually one expresses D in terms of media viscosity η as

$$D = \frac{2dkT}{\alpha} \tag{8}$$

with d = 2 (for 2-dimensional space) and $\alpha = 6\pi r \eta$ (Stokes law), where r is the radius of considered sphere particles. Therefore, from eq. (7) and (8)

$$\tau = \frac{2m}{\alpha} \tag{9}$$

In the case of latex spheres with radius $r \sim 10^{-6}$ m immersed in water with $\eta_w = 1.00 \cdot 10^{-3}$ Pa·s (20°C) we find $\tau \sim 10^{-7}$ s.

Thus the presented model

- i) correctly reproduces the known diffusion law,
- ii) gives the estimation of time τ between consecutive collisions in the system as the simple function of macroscopically measured quantities (e.g. temperature and diffusion constant).

The relation in eq. (6) can be checked via numerical simulation of the Brownian motion in media with different viscosities. In this the way one can find the sufficient number of particles in the ensemble we should observe in real experiment to obtain reasonable results, i.e. results being in agreement with diffusion law. If the number of investigated particles is too low one observes significant departures from the linear behaviour $\langle r^2 \rangle$ vs time [4] what may frustrate students in lab as they basically find from the experiments that the linear dependence in diffusion law is very suspicious.

Therefore we simulated the time series $\{\Delta x^{\alpha}_{i}\}$ in the iterative way:

$$x^{\alpha}_{i+1} = x^{\alpha}_{i} + \Delta x^{\alpha}_{i}$$

where Δx^{α}_{i} are generated as the random gaussian numbers $\mathcal{M}(0, \sigma)$ with the standard deviation σ obtained from eqs. (4) and (5) as

$$\tau = \tau \left(\frac{kT}{m}\right)^{\frac{1}{2}}$$
(11)

To avoid enormous number of steps in computer modelling (in the case of water the number of steps $N = t/\tau \sim 10^7$ per second) all simulations were performed for viscosity of an artificial medium $\eta = 10^{-2} \eta_w$ changing numbers of particles from n = 10 up to n = 180. The corresponding plots $\langle r^2 \rangle$ vs t are shown in Figs 1a – 1c.

Fig. 1a. Simulated runs for n = 10.



Fig. 1b. Simulated runs for n = 60.





Each figure shows 12 randomly chosen runs with **a**) n = 10, **b**) n = 60 and **c**) n = 180 particles immersed in the liquid. Straight line represent the diffusion law (for $n \rightarrow \infty$). One recognizes that the length of observation time is not so important as the number of observed particles. For $n \sim 10$ the range of linear dependence $\langle r^2 \rangle$ versus t is difficult to determine at all. For quite short observation time as 7 s many runs don't reveal the linear dependence and even if some of them do, their slopes differ from the theoretical value up to 50%. For $n \sim 60$ the linear dependence $\langle r^2 \rangle$ versus t for most runs is revealed for t < 20 s, but a good accordance with the theoretical value of the diffusion constant within 10% one can obtain for t < 10 s. It is not surprising therefore that experimental data for n = 5 particles (Fig. 2) does not support the Einstein – Smoluchowski law, i.e the linear dependence between $\langle r^2 \rangle$ and t.

If *n* increases up to ~ 200 the range of linear dependence also increases. For n = 180 the linear relationship approaches t = 40 s (see Fig 1c.).

It is worth to notice that in student lab with the standard equipment it is virtually impossible to follow the trajectories of more than few particles in 2 hours sessions.

III. Artificially Increased Statistics

There may exist a 'Life-belt' for students who are not able to take data from more than $n \sim 10$ particles during one lab. We call it Artificially Increased Statistics (AIS). The main idea of AIS is that the statistics is built initially from the data of the one particle trajectory. Its basic rules are shown in Fig. 3. For instance: if the observation time t = 30 s and the sampling time $\Delta t = 0.3$ s then one can obtain for one particle the following increased statistics:

100 displacements	for $t = \Delta t = 0.3$ s
99 displacements	for $t = 2\Delta t = 0.6$ s
2 displacements	for $t = 99\Delta t = 29.7$ s
1 displacement	for $t = 100\Delta t = 30.0$ s

Then this statistics is averaged over all *n* considered particles. Even if *n* is small ($n \le 10$) the overall number of displacements entering statistics is large enough to fulfil the linear dependence expectation.

This phenomenon is shown in Fig. 4 (data taken from the real experiment with water and glycerine). The comparison with plots in Fig 2. shows the significant improvement of the linear dependence law.

Fig. 2. Plots $< r^2>$ versus time averaged for 5 particles. Samples of experimental data for latex spheres of diameter of 850 nm immersed in water and water solution of glycerine (taken from [4]). Numbers in parenthesis correspond to expected theoretical values



Fig. 3. The basic idea of the AIS. The dots show a sequence positions of one particle. The blue lines represent displacements taken into account when calculating $\langle r^2 \rangle$ for $t = \Delta t$. The red lines correspond to displacements used to calculate $\langle r^2 \rangle$ for $t = 2\Delta t$ and the green ones show displacements used to calculate $\langle r^2 \rangle$ for $t = 3\Delta t$, etc.






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Inquiry into Application of the Spreadsheet Model Experiments in Physics Education

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Abstract

Paper presents results of Spreadsheet Model Experiments creation and verification of their applicability at school praxis. The objects of research are models created in Microsoft Excel Spreadsheet environment – possibility of their usage at Secondary Grammar School Education.

The basis for work was an analysis of the Physics textbooks for Secondary Grammar Schools in Slovak Republic and a questionnaire with the view of Physics teachers at physical phenomena modeling, which brought us an inspiration for own models creation.

We verified created Excel Spreadsheet Model Experiments by small pedagogical research at some Secondary Grammar Schools. There were instructions for teachers and worksheets for students prepared as a part of the Spreadsheet Models performance.

Material types of models are mainly used in physics education at Slovak secondary schools at the present time. Graphs, drawings and schemas represent other commonly used types of models. Information and communication technologies (ICT) and teaching ICT provide some new ways of modeling in physics education. Computer programs are able to replace a difficult calculation and process vast bulk of data. Software proves a visualization of the frequently complicated mathematical formulas in physics. Spreadsheet program environment (for example Microsoft Excel in the Microsoft Office suite and Calc from the Open Office suite) is the one of the possible options to further the objectivities of modeling in physics education. Probably every personal computer has a spreadsheet program and therefore we have an easily available tool for the making and using of mathematical models. There are many spreadsheet programs in hand [5].

To prepare a set of spreadsheet model experiments from the selected parts of secondary grammar school physics in relation to the curricula and to verify these models in school praxis were our tasks.

1 Spreadsheet model experiments

From our point of view, *the spreadsheet (or quantitative) model experiment* (SME) is a mathematical model of the physics phenomenon made in a spreadsheet program environment. It follows instructions of the modeling: original – abstract model – mathematical model – design algorithm – computer program – model. The basis of a model is an equation or a system of equations. The variations of input parameters for the applied model equations modify output data such as a graph and/or numbers.

SME respects the principles of experiment preparation in physics education, too: to have a goal, demonstrativeness, color balance, correctness, appropriateness ...

In the process of a model construction the analysis of the secondary grammar school physics curriculum has been accomplished at first. The next steps were:

- 1. selection of suitable physics phenomena;
- 2. didactic goal setting of a model;
- 3. creating of a model in spreadsheet environment;
- 4. creating of a worksheet for students with the structure: a short theory of phenomena, directions for the model use, physics tasks for the student to work out individually;
- 5. creating an accompanying document for teachers with the structure: comprehensive curriculum, motivation, student knowledge requirements and purpose of the model, instructions for the use with a picture of the expected model environment, suggestions for application in the teaching process;
- 6. arrangement of conditions for using of the models in physics lessons;

7. verification of the model in the teaching process.

By using SME in physics education we expect to:

- reduce an amount of mathematical calculations, therefore a way to the core of physics phenomena is quicker;
- increase students' activity during and excluding the lessons;
- obtain a lot of interesting excercises;
- include the model in the parts of teaching process (motivation, explanation, exercise, fixation and assessment);
- enhance mathematical calculations with graphics.

2 Inquiry into application process

With our expectation we accomplished the pilot research of the application spreadsheet model experiments. The goals were to obtain feedback about prepared models and to get the teachers' and students' opinion on teaching with spreadsheet modeling:

- Do SME help students make sense of educational theme on the required level?
- Do students give priority to using models before the classical teaching method?
- Is working with the spreadsheets complicated?

• What is the opinion of teachers on application of SME as a mean of object teaching?

To collect the information we used an interview method, a questionnaire method and an observational method. Students worked with SME and the worksheets. After handing over the filled-in worksheets, students were given the questionnaire about models. This way we obtained the observations and ideas of possibilities of using computers and spreadsheet models in physics lessons. Teachers filled-in another questionnaire about modeling in their physics teaching.

This pilot project was done by 5 spreadsheet model experiments with 6 teachers and two groups of students at two grammar schools:

• Group 1: 23 students of regular third year class.

• Group 2: 20 students from first year class focused on mathematics and physics.

It was realized in a computer classroom. Maximum two students sat at one computer.

3 Research results

The student worksheet had multiple-choice questions, physics tasks with an unknown quantity and questions with an open answer. The final question was about student internal opinion on the model.

There is one example with the percentual results of Group 1 and Group 2 of correct answers for the spring oscillator model below.

Group 1: Tasks 1 and 2 were multiple-choice questions about the dependency of physics quantities. Tasks 3 and 4 were simple physics tasks with an unknown quantity. Students had problems with reading the graph, with the axis assignment of quantities. Task 5 was about damped oscillations.

Group 2 worked with models out of their school in our department.

Other tested spreadsheet model experiments were: Hydrostatic pressure, Body motion and friction, Electric potential of point charge and In-line superposition of harmonic oscillators.

Spring oscillator SME



Fig. 1. Environment of spring oscillator spreadsheet model experiment.

100% -			_	_		100% -		_		_	
Group 1						Group 2					
50% -		_			_	50% -	_	_			
0% -						0%					
070	1	2	3	4	5	078 -	1	2	3	4	5
□no reply in %	0	0	21,7	26,1	4,4	□no reply in %	0	0	0	0	0
■incorrect in %	4,3	8,7	21,7	34,8	30,4	■incorrect in %	30	30	60	10	0
□correct in %	95,7	91,3	56,6	39,1	65,2	□correct in %	70	70	60	90	100
task number				task number							

Fig. 2. Percentual results of correct answers for the spring oscillator spreadsheet model experiment for both Groups.

Conclusion

We found out that students had been highly attracted by the spreadsheet model experiments – quantitative mathematical modeling in Excel – and they had considered the prepared models to be a suitable support for educational methods in physics. The students would also appreciate if more themes in physics were prepared by means of quantitative modeling. Computer was one of the motivating elements for them. On the other hand, some students had problems to read the graphs.

When asked, physics teachers appreciated the fact that models were very illustrative and helped the students understand the core of surveyed physical phenomena. A set of prepared spreadsheet model experiments means a significant contribution for teachers from the school praxis. It helps students understand complex physical topics and the prepared worksheets represent an appropriate instrument for their self-contained practical training, too.

But the connection of the spreadsheet model with a real-world phenomenon has a higher didactical value of the model experiment for the knowledge acquisition in physics education. And vice versa the real experiment is supplemented with a model, too. These ideas was applied in publications Integrated Science through Experiments, e.g. [2].

This approach is the one facet of the modeling – *Model Research* (Students investigate a specific area to gain a deeper understanding of some behavior and learn how to use what has already been created or discovered). The other two facets – *Model Analysis* and *Creative and Empirical Model Construction* – are the two steps to achieve the objective of modeling: Students investigate meaningful and practical real-life problems. [1]

In our opinion, this pilot research was successful and we will continue in this theme of physics education research. We have to do some structural changes of student worksheets and questionnaires, prepare other spreadsheet model experiments, prepare instructions for reading graphs and considerably enlarge a research group of students.

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Investigating Aspects of Modelling in Electrostatics

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Abstract

Research shows that the knowledge and use of models and modelling by teachers is limited particularly for predicting phenomena. An area of concern relates to the effective use of microscopic models by teachers to explain and predict physical phenomena in several areas including electrostatics. In this context we developed and applied a sequence of three simulated models focusing on polarization embedded in a model based instructional unit aiming at enhancing primary student teachers' understandings both about polarization and the predictive power of models. Selected pre- post tests and group interview results are presented showing students' cognitive evolution and suggesting moderate success of this model-based intervention in enhancing the use of models by students.

Introduction

Recent research indicates that teachers' knowledge of models and modelling is limited (Van Driel & Verloop 1999, Cullin & Crawford 2003). In particular, the predictive function of models is hardly understood (Treagust et al 2002, Cullin & Crawford 2003). Recently there is an interest for developing and applying innovative approaches aiming at facilitating teachers' use of models in treating physical phenomena and potentially apply modelling procedures in their classes (Justi & Van Driel 2005).

Regarding models and modelling, an area of concern relates to the long-standing didactical problem of the effective use of microscopic models by teachers and students to explain and predict physical phenomena in school topics such as electrostatics. Electric polarization and related phenomena in particular, is an area in which student teachers face difficulties in providing explanations and predictions (Barbas & Psillos 2003).

In this context we have been engaged in a series of "teaching experiments" (Steffe & D' Ambrosio 1996) including both development and research by developing and applying successive interventions to small groups aiming at enhancing student teachers' knowledge and use of microscopic simulated models in electrostatics and their understandings of the function of models. By investigating in depth students' reactions we aim at revealing crucial points and learning obstacles so that instruction will be gradually adapted to students' thinking. We present here a sequence of simulated causal models embedded in a 3 hours instructional unit aiming at enhancing student teachers' understanding of polarization and the predictive power of models.

Overview of the Representation of Polarization

Well-known textbooks like Serway (1990) and Hewitt (2002) usually adopt static pictorial models to represent the microscopic level when a charged body is nearby an uncharged one (figures 1a, 1b).



Fig. 1. Representations of dipole formation (a) Serway, (b) Hewitt, (c) a web-picture, (d) Chabay & Sherwood

The concept of "dipole" is introduced and in figures 1a, 1b dipoles seem to have the same shape even though their distance from the external charge is different. However, Chabay & Sherwood (2002), as well as some representations in the web (2006), propose the dipoles to be such deformed, as they are closer to the external charge (figures 1c, 1d). In some representations though there is no orientation of the dipoles (figures 1a, 1c) while in others appears (figures 1b, 1d).

Static models usually avoid the drawing of the forces on the atom or on the dipole that comprises the cause for the attraction between an uncharged and a charged body. Forces are introduced rather recently, mainly in Physlet applets (Wolfgang & Belloni 2003) (figure 2).



It appears that there is not a unanimous and comprehensive approach to the modelling of dipoles and dipole formations. Besides, research reveals students' difficulties in polarization (Barbas & Psillos 2003). To improve such situation we opted for didactically transformed comprehensive representations of polarization at introductory level.

DEVELOPMENT OF SIMULATED MODELS

We opted to develop three innovative simulated causal models representing electric polarization and specifically the behaviour of an atom and forces exerted on a dipole and an

insulator when an external charge is placed anywhere near them. The aim was to have a sequence of models with which students could study the attraction between an uncharged and a charged body.

The introduction of the dipole was considered to be necessary, as we wanted to represent the forces exerted as the cause and the explanatory framework for the attraction between uncharged and charged bodies. Specifically, we structured the models for providing a smooth passage from the microscopic to the macroscopic level. We thus designed one model that shows the deformation of the electronic cloud in an atom; afterwards we pass to another model that shows the formation of a dipole upon external charge and then a third one showing an insulator when there is nearby an external charge. Following Chabay & Sherwood (1995) we developed the sequence: model of atom – model of dipole (figure 3), as the dipole (figure 3c) is appropriate for emphasizing the "most important aspects of polarization".



In simulations 1 and 2 the user can choose and move an external charge anywhere nearby to an atom or dipole respectively (figure 4). The red circle of the atom represents the nucleus and the blue circle represents the electronic cloud. The white dotted circle indicates the closest position of the external charge to the atom or dipole. When an external charge is moved close to the atom, the electronic cloud is deformed from spherical symmetry towards (or away) to the external charge, as being attracted (or repelled) to it depending on the polarity of the charge.



Fig. 4. Atom (left) and dipole (right) representations upon external charge

The red and blue circles of the dipole show the center of positive or negative charge. When an external charge is moved close to the dipole, the two poles separate due to Coulomb interactions. The attractive force appears bigger than the repelling one, obeying the rule of Inverse Square for distance.

In simulation 3 the user can move an external charge anywhere nearby to an uncharged insulator (figure 5).



Fig. 5. Dipoles in an insulator

Both attractive and repulsive forces exerted to each dipole are indicated. Our aim was to put the students in a process of predicting the attraction between the uncharged and the charged bodies taking into account both the attractive and the repulsive forces.

TEACHING AND INVESTIGATING THE MODELS

A sample of 10 university pre-service primary education student teachers in Thessaloniki, Greece, was engaged in instruction with the simulated models. These students, opted for a larger program, worked in small groups with specially developed worksheets. Here we mainly focus on one 3 members group (S1, S2, S3). The main features of the interplay between instruction aiming at enhancing the use of models by students for predicting phenomena and monitoring of students' progress is shown in Diagram 1.

In carrying out their worksheet, the three students initially provided predictions on tasks in which they were asked to answer what would happen between an uncharged and a charged balloon; then they handled the three simulated models and tried to predict the same phenomenon again. After the second interview the real experiment with balloons was performed. Finally, the students compared their initial predictions with them after working with the models and the experiment.



Diagr. 1. Structure of the intervention

Data were obtained by pre- post written students' answers on the questions of the worksheets and analysis of tape recorded in depth group interviews.

RESULTS

Students were asked to predict what might happen between an uncharged balloon B and a negatively charged balloon A both attached to strings from the ceiling (figure 6).



In the first interview students S1 and S2 thought that the balloons will not interact and chose figure a, while S3, chose the option f. The students justified their answers as follows.

Teacher (T): What did you answer?

S1: As the balloon B is uncharged there will be no attraction or repulsion.

S2: I agree! Even though the one balloon is negatively charged there will be no interaction as the other balloon is uncharged.

T: What about you?

S3: Even though I have written that the negatively charged balloon will repel the uncharged balloon, now I agree with the girls.

After working with the models, students were asked to carry out again their predictions on the task.

T: What did you answer?

S2: That finally there will be exerted attractive forces between the balloons and we will see them coming near; I would choose now the figure c.

T: When you say finally what do you mean?

S2: The exerted forces are not only attractive. Simply, the attractive forces are bigger than the repulsive.

S1: They are bigger because the distance between the opposite charges is smaller!

T: What do you think?

S3: *I* think that the charged balloon will exert attractive force to the uncharged one. I would choose know the figure d.

S1: No! According to the third model the uncharged balloon always will be attracted to the charged balloon A and because of the third law of Newton the balloon A, also, will be attracted to the uncharged balloon.

S3: I didn't think about it at all.

It seems that S1 and S2 predicted correctly the attraction between the balloons referring both to repulsive and attractive forces while S3 considered that the charged body attracts the uncharged and didn't speak about the existence of the repulsive forces.

Regarding the predictive use of models these students were asked to reflect on the features of the models that helped them in interview 3.

T: *Did the models help you predict correctly?*

S1: Yes!! While I was sure that there wouldn't be any interaction between the balloons, after working with the models I wrote that the balloons should be attracted to each other. The experiment also showed that!!

S3: When I saw the experiment I realized that I didn't make a right prediction...(she laughs). I wrote that only the uncharged balloon would move close to the charged one...

T: You?

S2: My prediction was right!

T: Now, can you underline the features of the models that helped you predicting?

S2: For my prediction the existence of the dipole and its behavior was important

S1: I can't say that the one model helped me more than the other. All the three models helped me. If I have to choose... may be the forces were the most important.

T: What about you?

S3: *The one with the atom. The deformation of the electronic cloud helped me more.*

It seems that S1, S2 recognized the power and employed successfully the models in their thinking while S3 was partially moved from her initial views. Besides, differential features of the models provided conceptual help to each student. Also, as expected, they used the real experiment in order to check their predictions.

CONCLUDING REMARKS

Following their engagement in the model-based unit the three student teachers succeeded in fulfilling their tasks by using the models. Reflecting on the models themselves, students considered them as conceptually helpful. Various features of each model, such as representation of deformation and forces appealed to each student's thinking. Similar results were found with the rest students of the sample as well. Having in mind the limitation of this small-scale study, we envision that this comprehensive representation of polarization, the required predictions before and after the introduction of the models, corroborated by real experimentation, facilitated students to understand both the specific content and the predictive power of models.

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Use of Computer Simulation as a Tool for Modelling Physics Experiments

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Abstract

Scientific understanding emerges from making and using models (David Crystal, 1990, Lasley.T.J. et .al 2002). The development and use of a model aids the lecture demonstration process and accelerates the understanding (Lasley.T.J.,Matczynski.T.J 2002).Computer modeling tools have immense power. Effects produced by physical modeling methods can be easily produced by computer simulation (Kumar 1996).

As a step towards creating a better understanding of laboratory practical in Physics with the aid of multimedia technology (Lakshmi & Sundararajan 2005), the authors have prepared computer-simulation of the procedure of an experiment in the curriculum of undergraduate degree course in Physics

There are a lot of model experiments available in the web. What is the necessity for developing a new one? The development of computer simulation to assist as a tool for laboratory practical is closely related to the nature of the curriculum of that particular university. This development should focus on the abilities of the student group. Hence the design of the simulation tool has to be need based and need specific.

INTRODUCTION

Physics is the subject, which deals with the laws governing nature. It is the only subject that pervades in the static and dynamic environment, analyses both theoretical and practical aspects of life, and can unite living and nonliving entities. The study of the theoretical aspects creates a strong base in the fundamental principles of nature. Providing hands on experience in an array of experiments in various branches of Physics develops the comprehensive skills of the students. The power of Physics lies in describing a great variety of phenomena by a limited set of fundamental laws and principles. The development and use of a model aids the lecture demonstration process and accelerates the understanding, exploration and invention stages of the learning process.

ACCESS TO INFORMATION

There is an all round development in the society we live. Today's scenario of education is totally different from the one we had in the last century .The methodology of teaching has undergone a lot of changes. In the present global scenario, with the wide use of computer, Internet and other facilities, there is no bound for the flow of information. Teachers no longer need to act as the storehouse of knowledge. The worldwide web claims the pride of providing an ocean of information. Knowledge resources are available for anybody who can access the Internet.

TEACHERS ARE EDUCATION MANAGERS

This situation does not imply that teaching is not at all required. Good teachers develop good students. In the emerging scenario of education, Teachers have to act as managers of the teaching and learning process. They have to act as a co-worker or co learner and perform the role of facilitators of knowledge. Teachers have to help students learn more in a given duration of time. Their role in education should be directed towards enhancing the environment to learn. This situation demands the application of suitable technologies that can assist the teacher in managing the educational enterprise.

MODELLING

In painting, drawing and photography, modeling refers to the use of light and shade to create the effect of the original object on paper. The idea of modeling is not to create the original system, but to create an understanding of the principles underlying the system (David Crystal, 1990) Scientific models are coherent units of structured knowledge. Scientific understanding emerges from making and using models (Lasley.T.J. et. al2002). Apart from the standard representational tools like physical

objects, verbal, mathematical, graphical and others, computer-modeling tools have immense power. (Hestenes,1996). The mental models of students are strongly influenced by visual imagery. Furthermore, most students today have extensive experience watching video. The computer can control, capture, and display video images on a monitor and allow students to take data from the screen a frame at a time (Redish 1993). Effects produced by physical modeling methods can be easily produced by computer simulation (Kumar 1996). The progress of science is linked with a better method of modelling that suits our environment.

LABORATORY PRACTICALS

Normally the laboratory curriculum in Physics involves a specified number of experiments to be done in a year. Let us assume that we have a class of forty-two students who have to finish off 18 experiments in an year. It is not economical to buy, maintain and repair ($42 \times 18 = 756$) sets of apparatus for one particular class alone. In most of the places, constraint in space also will limit the number of apparatus that can be used.

Hence, a system of cyclic rotation is followed in the lab. The total experiments are divided into three cycles. The students are divided into N number of groups with n students in each group, such that

 $N \ge 3 = 18$ and $N \ge n = 42$.

Hence it will take N classes to complete N experiments.

The basic drawback of this system of only Equipment based Laboratory Practical (ELP) is that in one particular practical class, all the 42 students are not doing the same experiment. Different batches of students receive different sets of instructions from the teacher. Hence there is a limitation on the peer group interaction.

The time allotted for doing a practical is limited. Apart from identifying the apparatus and doing the experiment, the student has to do the calculation within the stipulated time. Only if the student knows the routine part of the practical, he can find some time and energy for problem-oriented thinking or application-oriented studies.

With this idea in mind, it was proposed that computer simulation could be used as a tool for providing pre practical orientation for the Physics experiments. Integrating Computer Simulation based Laboratory Practical (CSLP) with the conventional Equipment based Laboratory Practical (ELP) in the present curriculum of the laboratory practical in Physics will modify the way learning takes place by providing better understanding (Lakshmi & Sundararajan 2005).

REQUIREMENT ANALYSIS

There are so many experiments available in the web.

Can we not choose one from the web and use it for providing pre practical orientation?

To find an answer to this question a survey was conducted and a questionnaire (Appendix I) was circulated to forty-five teachers teaching Physics at various levels. All of them felt that a pre practical orientation class would help the students know the details of the procedure to be followed before entering the lab. From the short-listed twenty people who use audio visual aids including computer simulation and who have gone through at least five free downloadable websites that offer simulation of Physics lab experiments using multimedia technology, the following data was collected.

Ninety percent of the teachers felt that the level of the experiments offered in the web is either too high or too low for giving pre practical orientation. The remaining ten percent of the teachers felt that the web materials could be used with minor modifications. But such people were not aware of the nature of the software used for preparation. But most of the multimedia presentations are available only as executable versions of the simulation and hence it is not easy to modify according to the needs of our curriculum.

The presentations have to be designed taking into account, the class in which a student is studying and the requirements of the curriculum.

PREPARATION OF THE SIMULATION

The authors plan to to design and develop an interactive system, which can be used for a better understanding of the Physics practical using multimedia Technology. As a first step towards this goal, the authors have developed a prototype of the multimedia presentation required for providing prepractical orientation and studied the performance of the simulation. This simulation focuses on the experimental procedure to be followed in the lab for "The StaticTorsion" experiment to determine the rigidity modulus of the material of the rod (Srinivasan 1996). This experiment is done at the undergraduate degree course in Physics.

PERFORMANCE ANALYSIS

The performance of this type of simulation can be assessed by the difference in the knowledge level of a student before and after presentation. A preliminary trial was conducted with two batches of consisting of ten students who have studied Static Torsion experiment in theory but have not done practical. Two question papers with multiple choice questions based on the important points that can be used as a measure of the understanding of the static torsion experiment were used as the tool for analysis (Appendix II and III)

The first batch of students answered the questions Appendix II before presentation and the questions in Appendix III after presentation. During this analysis if one question paper turns out to be easier than the other one, the results will be skewed. To avoid this error in the measurement of the performance, the second batch of students were asked to answer questions in Appendix III before presentation and Appendix II after presentation.

A students t-test was conducted with the observations (Gupta and Kapoor,1996). The calculations are summarized in Table I (Appendix IV).

Questionnaires of equal difficulty were given before and after presentation.

The points scored by the students before (x_1) and after (x_2) the presentation were used as the measure to check the use of simulation to provide pre practical orientation.

The number of students subjected to the test was equal and less than thirty for both pre presentation and post presentation analysis. The mean (d) and standard deviation (σ_s) of the difference between the points of the two questionnaires (d) are computed.

d =
$$(x2 - x1)$$

d' = mean of the d values = 3.3

 $= \Sigma (d - d')^2$ <u>n-1</u>

σs2

Assuming that the students are not benefited by the presentation the mean of the difference between the marks of the two tests (μ) is zero. Then

= 8.9579

t cal =
$$\frac{(d' - \mu)(n)^{1/2}}{\sigma s}$$
 = 4.9309

The number of degrees of freedom v = n-1 = 20 - 1 = 19

For v = 19, the tabulated value t_{0.05} = 2.09 As the calculated value of t_{1.15} t_{0.05} the difference between sample

As the calculated value of $t_{cal} > t_{0.05}$, the difference between sample means is said to be significant at 5% level of significance. The statistical calculations on t test indicate that the students are benefited by the presentation. Hence computer simulation of the experiments can be used as a tool for pre practical orientation.

ADVANTAGES OF THE SIMULATION

In the context of Physics education, this modeling with the use of computer simulation helps to produce better understanding of basic concepts, providing hands on experience in a simulated environment with provision for repeating the experiment any number of times thereby achieving an effective use of laboratory time leading to problem oriented thinking and application oriented studies. The main advantage lies in the fact that all the students sitting before the computer can get the same set of instructions in the lab gaining an advantage over time. Interested students can work even from home. When they enter the lab the students are well informed of the experiment and hence can concentrate on developing practical skill.

CONCLUSION

Computer simulation of the experiment to be done in the practical class using multimedia Technology can act as a tool for laboratory practical. This development should focus on the nature of the curriculum and abilities of the student group. Hence the design of the simulation tool has to be need based and need specific.

PLANS FOR THE FUTURE

This pilot study of preparing the simulation and analyzing the performance produces enormous effect on the future plan of the authors to develop an interactive CSLP package incorporating the following special features

- Database containing the list of experiments
- Slide show relating the principle behind the experiment
- Help provided to all the apparatus used in the experiment
- Provision to changes the external parameters affecting the system along with a set of default values
- Multimedia file enabling the students to make the required connections
- Stepwise computational examples
- Set of computer simulated problems relating to the experiment.
- Applications of the principle behind the experiment

Preparation of CSLP package is a time consuming process and involves the combined efforts of experienced Physics teachers and Animation experts. The efforts of the future will overcome the limitations on the number of students and the number of experiments of the present study on the issues related to generalization.

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APPENDIX I

REQUIREMENT ANALYSIS - QUESTIONNAIRE TO TEACHERS

- 1. What is the level of your students?
 - a) Secondary
 - b) Higher secondary
 - c) Under graduate
 - d) Postgraduate
- 2. How long do you teach?
 - a) Less than five years
 - b) 5-10 years
 - c) 10-15 years
 - d) Above 15 years

3. Do you feel that a pre practical orientation class will help the students know the details of the procedure to be followed before entering the lab?

- a) Yes
- b) No

4. What method you follow to impart knowledge of the experiment to be done, prior to the lab session?

- a) Lecturing
- b) Showing the actual apparatus
- c) Physical models
- d) Computer simulation

5. Have you ever gone through the free downloadable websites which offer simulation of Physics lab experiments?

a) Yes

b) No

- 6. If yes, how many are suitable for the teaching requirements of your curriculum?
 - a) 0 5
 - b) 6 10
 - c) 11 15
 - d) More than 16

7. Indicate the suitability of these web materials for using in a pre practical training class of your curriculum

- a) Suitable without any modification
- b) Suitable with minor modifications
- c) Level is either too high or too low
- d) Not suitable for your requirement
- 8. What is the nature of software used for simulation?
 - a) Executable versions only
 - b) Source code that can be modified
 - c) Source code that cannot be modified.
 - d) Not aware of the nature of the software.
- 9. Do you feel that there is a necessity for preparing computer simulation that suits the needs of your curriculum?
 - a) Yes
 - b) No

APPENDIX II

PERFORMANCE ANALYSIS - QUESTIONNAIRE I

- 1.What is the modulus of elasticity associated with Static Torsoin experiment
 - a) Young's modulus
 - b) Rigidity modulus
 - c) Bulk modulus
 - d) Poisson's ratio
- 2. Can we do this experiment with a tube containing mercury?
 - a) Yes
 - b) No
- 3. The instrument used for measuring the radius of the wheel is
 - a) Screw Gauge
 - b) Vernier calipers
 - c) Scale
 - d) Protractor

4. What is the shift for no load?

- a) Zero
- b) 4.8cms
- c) 2.4 cms
- d) Infinity
- 5. While winding the thread in the clockwise direction, the position of the mirror changes because, the rod,
 - a) Rotates
 - b) Elongates
 - c) Contracts
 - d) Twists
- 6. Do we get the same readings for loading and unloading?
 - a) Yes
 - b) No
- 7. When the distance between the scale and mirror changes the shift for a particular load
 - a) Remains the same
 - b) Changes
- 8. What is the nature of the load depression graph?
 - a) Straight line
 - b) Parabola
 - c) Hyperbola
 - d) Ellipse.
- 9. The reading of the scale does not change, when the angle of twist is zero
 - a) True
 - b) False
- 10. The unit of rigidity modulus is
 - a) Newtons
 - b) Newton Meter
 - c) Newton/Meter
 - ^{l)} Newton/meter²

APPENDIX III

PERFORMANCE ANALYSIS - QUESTIONNAIRE II

- 1. The length of the rod used in this experiment can be
 - a) Less than 0.5 cms
 - b) 0.5cms to 1.5 cms
 - c) 0.5m to 1.5m
 - d) Greater than 5m
- 2.Is this method suitable for gases?
 - a) Yes
 - b) No
- 3. What is the instrument used for measuring the radius of the rod?
 - a) Screw Gauge
 - b) Vernier calipers
 - c) Scale
 - d) Protractor
- 4. What is the action of the wheel?
 - a) Rotate the rod
 - b) Twist the rod
 - c) Elongate the rod
 - d) Contract the rod
- 5. Can we change the position of the telescope during loading and unloading?
 - a) Yes
 - b) No
- 6. When the distance between the fixed end and the mirror changes, the shift for a particular load
 - a) Remains the same
 - b) Changes
- 7. The distance of the scale from the mirror should be
 - a) Less than 5 centimeters
 - b) 50-150 cms
 - c) 5 metres
 - d) Greater than 5 metres.
- 8. The angle of twist is
 - a) Directly proportional to the shift
 - b) Proportional to the square of the shift
 - c) Proportional to the square root of the shift
 - d) Inversely proportional to the shift
- 9.Can we use a microscope instead of a telescope in this experiment?
 - a) Yes

b) No

- 10. When the distance between the mirror and the fixed end is halved, the rigidity modulus of the rod
 - a) reduces to half the value
 - b) increases two times
 - c) is squared
 - d) does not change

APPENDIX-IV

PERFPRMANCE ANALYSIS

X 1	X 2	X 2- X 1	d- d'	$(d-d')^2$
18	20	2	-1.3	169
12	18	6	2.7	7.29
10	16	6	2.7	7.29
14	20	6	2.7	7.29
18	16	-2	-5.3	28.09
12	16	4	0.7	0.49
18	20	2	-1.3	1.69
10	16	6	2.7	7.29
16	20	4	0.7	0.49
14	20	6	2.7	7.29
20	18	-2	-5.3	28.09
12	16	4	0.7	0.49
10	16	6	2.7	7.29
12	16	4	0.7	0.49
20	20	0	-3.3	10.89
10	14	14	4	0.49
14	12	12	-2	28.09
20	20	20	0	10.89
12	18	18	6	7.29
10	16	16	6	7.29
	SUM	66		170.20
Ν	MEAN	3.3		8.51

$$\sigma_{\rm S}^2 = \Sigma (d - d')^2 = 170.20 = 8.9579$$

$$\sigma_{S} = 2.993$$

$$t = (d'-\mu) * n^{\frac{1}{2}}$$

$$= 3.3 * (20)^{\frac{1}{2}}$$

$$= 4.9309$$

SNAP SHOTS







Helical Learning Model

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Abstract

A popular model employed to represent the learning process is typically portrayed as a fourstage process signified by a cycle in a two-dimensional circular path. This cycle can be repeated by revisiting topics at increasing levels of sophistication in order to produce what is known as a spiral curriculum. In this presentation, a variation of Kolb's two-dimensional learning cycle model is offered that represents the learning cycle as if it were a threedimensional spiral, or helix, with successive turns associated with Bloom's Taxonomy levels. This representation is explored and developed to provide an alternative means to visualize the learning process in the hope that the new perspective may lead to a more comprehensive model for the learning cycle and to a broader implementation of more effective curricula and teaching practices.

Introduction

Physics Education Research (PER) in the United States has made a substantial contribution to our understanding of common difficulties students encounter when trying to learn physics and has also produced strategies to address some of these difficulties [1,2,3]. Redish appears to be one of the first to attempt to synthesize a comprehensive model as a framework in which to interpret and apply PER findings [3,4,5]. In the application of these findings, he acknowledges the importance of individual learning styles and using a variety of approaches to effectively "match the impedance" of different styles. This paper presents a model that unifies four fundamental learning styles and a corresponding learning cycle with a set of cognitive objectives for higher level learning outcomes. The purpose of the model is to provide an alternative representation of the learning process and a framework in which to more effectively apply both conventional and research-based strategies in the classroom.

Learning Styles

A systematic study of learning styles was carried out by Kolb [6], and his cyclic learning model has been widely applied in the Engineering Education community for more than a decade [7, 8]. Based on the work of John Dewey, Kurt Lewin, and Jean Piaget, its central idea is that "learning is the process whereby knowledge is created through the transformation of experience", or more descriptively, "Learning, and therefore knowing, requires *both* a grasp or figurative representation of experience and some transformation of that representation" [6, p.38, 42]. This does not sound very different from Arons, "to help the learner assimilate abstract concepts, it is essential to engage the learner's mind in active use of the concepts in concrete situations. The concepts must be explicitly connected with immediate, visible, or kinesthetic experience" [1, p.38]. In Kolb's structural model, there are two complementary modes of grasping experience on one axis, and two complementary modes for transforming the experience on a second axis, orthogonal to the first (figure 1). The experience may be concrete and external (perceptions) or abstract and internal (conceptions), and the transformation may be by intention (reflective and internal) or by extension (active and external).

These two opposing dialectic polarities give rise to four possible combinations of experience and transformation, and a complete cycle composed of all four combinations is supposed to produce the highest level of learning. Kolb created an instrument to assess which modes students use in learning situations and found that most individuals exhibit a preference for one of the four combinations, or learning styles. If you have taught physics laboratory sections, you have probably witnessed (concrete experience) students responding to the apparatus in front of them in two distinct ways. One is characterized by the student sitting back and watching (reflective observation) while another student immediately begins to play with it (active experimentation). Upon witnessing a scene like this, you might have responded to this experience in one of the same two ways: noting that the distinct behaviors represent a recurring pattern (reflective observation), or by initiating some action (active experimentation) that might end the distraction. There are at least two arguments for the adoption of a pedagogic approach that recognizes different learning styles. One is that by addressing all four

possible learning styles in a cycle of classroom activities, more students will be able to master the course material. The second is that by having each student practice all four learning modes, they can become more proficient and successful learners. By systematically incorporating the experiential phase of the learning cycle in classroom activities, we may also help achieve the more "thorough interweaving of the physics with explicit connections to the students' experience" called for by Redish [3, pp. 61-62].



Figure 1: Kolb's Fundamental Learning Modes

Learning Cycles

Kolb's learning cycle is not the only one that has been proposed, but it does appear to be the most deeply anchored in cognitive psychology and philosophy. One example of a simplified learning cycle for science has been presented by Lorsbach [9] (figure 2). A noteworthy aspect of the latter model is that it includes an explicit recognition of the need to identify pre-existing knowledge which may not be compatible with the concepts we are trying to teach. The identification of existing physical "knowledge" is also explicitly recognized in the three-stage cycle of "elicit/confront/resolve" utilized by the PER Group at the University of Washington [10]. Although this element does not appear explicitly, it can be clearly recognized in Kolb's introduction to the model, which anticipates some salient PER findings: "In many cases, resistance to new ideas stems from their conflict with old beliefs that are inconsistent with them. If the education process begins by bringing out the learner's beliefs and theories, examining and testing them, and then integrating the new, more refined ideas into the person's belief systems, the learning process will be facilitated" [6, p.28].

He goes on to describe two mechanisms for the adoption of new ideas that were previously identified by Piaget as integration and substitution. Kolb further states, "Ideas that evolve through integration tend to become highly stable parts of the person's conception of the world. On the other hand, when the content of a concept changes by means of substitution, there is always the possibility of a reversion to the earlier level of conceptualization and understanding, or to a dual theory of the world where espoused theories learned through substitution are incongruent with theories-in-use that are more integrated with the person's total conceptual and attitudinal view of the world" [6, p.28-29]. How these "theories-in-use" can function to inhibit effective physics learning has been addressed in more detail by Redish [3, Chs. 2-3]. A concise summary of learning cycle models for pre-college science teaching has been presented by Sunai [11].

Figure 2: Lorsbach's Learning Cycle



Learning Cycle Variations

In a more recent study, it was noted by my co-authors that one of the challenges associated with the effective application of evolving digital pedagogies was to effectively harness the power of conceptualization and modeling in the learning process [12]. After exploring Kolb's cyclic learning model and reviewing their experience with the results of problem-based-learning, they concluded that "conceptualization" should be re-positioned from a single stage to a central element in the learning cycle (figure 3).





A critical limitation of any two-dimensional cyclic learning model is that the final stage of the cycle appears to return the system to its initial state. If a learning "cycle" has been successful, the process must bring the learner to a new state in their concept-space. That the learning cycle is more of a spiral than a circle was perhaps first formally recognized by John Dewey, and this is represented in a depiction of Dewey's model of experiential learning in figure 4, adapted from [6, p.23]. A "spiral" approach to the attainment of educational objectives was proposed by Bruner more than forty years ago [13]. Student difficulties with the assimilation of fundamental scientific concepts have been addressed extensively by Arons [1]; he recognized that the learning process was very slow for most students, and required repeated encounters with the concepts in increasingly sophisticated contexts. In consonance with Bruner, he strongly advocated spiraling back (through the course material and/or the curriculum) for these reviews. A spiral approach to producing new curricula adopted by Lillian McDermott and the PER Group at the University of Washington was acknowledged by Redish as cycling "in a helix of continuous improvement" [14], and a helical format was employed by Collura, et.al. to represent a Multidisciplinary Engineering Foundation Spiral [15].

Figure 4: Dewey's Model of Experiential Learning



Cycle or Spiral?

Although the helix has been used as a model for curriculum structure and development, it does not appear to have been applied as an alternative model for representing the learning cycle. In this application however, the helix can provide a direct correspondence between successive turns and the levels of Bloom's hierarchy of educational objectives. The Bloom Taxonomy (table 1) was developed to provide a hierarchical structure or ranking of cognitive abilities [16].

Bloom level	category	description
1	knowledge	recall of information/ideas
2	comprehension	meaning of information/ideas
3	application	use of information/ideas
4	analysis	resolution of information/ideas
5	synthesis	recombination of information/ideas
6	evaluation	judge value of information/ideas

Table 1: Bloom's Taxonomy of Cognitive Objectives

In a geometrical representation of this model, the Kolb learning cycle in the x-y plane is combined with the Bloom model in the z direction, and the concept to be developed is aligned with the axis of the helix, thus assuming the central role suggested by Cocke. A learner's progression along (or projection on) the axis of the helix (z) could be portrayed in either a discrete or continuous fashion. A continuous trajectory might result from the gradual accumulation of knowledge and be modeled by assigning a z-component to the stages in the Kolb cycle. A discrete learning event may occur at any point in the cycle where there is a resonance between the conceptual configuration of the learner and the confluence of conditions in their environment and be represented by a singularity (iz) in a complex Kolb plane. In this picture, the gradual "dawning of enlightenment" and the "Eureka moment" could be considered as alternative representations for a reconfiguration of the learner's selfconstructed concept-space. If this reconfiguration were to be brought into correspondence with a real physical process, such as the development of new neural connections, some investment of physical energy would be required. It might then be possible to associate a latent energy with the reconfiguration process, and we could begin to speak of the binding energy of the concept. This viewpoint may provide a mechanism to explain the persistence of the common naïve conceptions that students bring to our classes and how these can inhibit further concept development. The geometry of this model also lends itself to representing of the idea of a "resistance to learning" in terms of an inductive self-impedance.

Harnessing the Helix

In an ideal application, the learning cycle would begin with a concrete experience (discrepant events are particularly effective in securing students' attention and exposing common naïve conceptions). The experience would be followed by activities that foster reflection, description, and interpretation of the meaning of the event. The next phase would be abstract conceptualization, where the event might be represented symbolically or explained in terms of more general ideas (schemas) or theories. The implications and/or practical applications of the ideas would be realized in the next stage of active experimentation. This experimentation leads into another 'cycle' with a concrete experience at a higher cognitive level than the previous event.

Many of the prescriptions provided by Arons [1] are consistent with this model and appear to have been incorporated into the more recent research-based curricula included in The Physics Suite [3]. Some of these curricula have been infused with computer-based laboratory activities and consequently are able to address all four learning modes in a progressive Bloom sequence. These curricula have achieved the largest learning gains. Table 2 presents a variety of conventional and research-based methods along with the associated learning styles addressed. This mapping is provisional and subject to modification. Activities that utilize group interactions can also address learning styles that are oriented toward concrete experience (I and IV), and some activities such as traditional "cookbook" laboratory exercises may address multiple styles, but not in a productive sequence.

Instructional Method	Kolb Learning Styles Addressed				
Traditional Lecture		II			
Lecture Demonstrations	Ι				
Interactive Lecture Demonstrations	Ι	II	III		
Peer Instruction	Ι	II	III		
Traditional Recitation		II			
Interactive Recitation		II	III		
Cooperative Problem Solving	Ι	II	III		
Tutorials in Introductory Physics	Ι	II	III		
Activity Based Physics Tutorials	Ι	II	III	IV	
Traditional Laboratory	Ι		III	IV	
RealTime Physics	Ι	II	III	IV	
Workshop Physics	Ι	II	III	IV	
Physics By Inquiry	Ι	II	III	IV	
Traditional Homework Problems			III		
Ranking Tasks and TIPER'S (ind.)			III		
Ranking Tasks and TIPER'S (group)	Ι		III		

Table 2: Learning Styles addressed by Instructional Methods

Conclusion

A wide variety of conventional and research-based methods are available to help us attain course objectives. Traditional instructional methods do not address the variety of learning styles utilized by our students and have not proven to be as effective as instructional methods developed from the findings of PER. However, some of the more effective methods, which integrate a sequential engagement of all four learning styles along with a progression in cognitive objectives, may be difficult to implement in some situations.

Kolb's structural model of the learning process provides a framework for selecting and sequencing course activities to increase productive learning outcomes for more students in any situation. The calibration of each successive cycle of learning activities with the Bloom cognitive levels can facilitate a more systematic progression of course activities, within a course as well as between courses and grade levels. The combination of these two strategies in a single model may help provide for a more systematic and successful application of the instructional methods at our disposal.

Acknowledgments

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How Much Should We Tell The Learners? Some Reflections On Modelling In Physics Education

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Abstract

Traditionally physics teachers and textbook authors have tended to avoid telling students and readers very much about the fundamental role played by mathematical modelling in explaining physical phenomena. This paper argues that learning can be made easier if the teacher is more forthright about the nature and status of the underlying models. Care should be taken when using words like 'law' to describe a model/theory. Macroscopic models need to be clearly distinguished from microscopic ones. Ideas will be illustrated by reference to particular models encountered in school physics.

Introduction

La science est l'asymptote de la vérité. Elle approche sans cesse et ne touche jamais. (Victor Hugo, William Shakespeare, 1864)

In its attempt to 'approach the truth', the most powerful tool available to the physicist is that of mathematical modelling which, in more recent years, has been enhanced by computational tools. The central role of mathematics in physics has been understood for at least four centuries.

Philosophy is written in this grand book. I mean the universe which stands continually open to our gaze. But it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics without which it is humanly impossible to understand a single word of it; without [this] one is wandering about in a dark labyrinth.

GALILEO GALILEI, The Assayer, 1623.

No one needs to be reminded that Newton's development of differential calculus was primarily to provide him with the tools for the formulation of analytical dynamics. The extraordinary advances in man's understanding of the material universe since Newton's time have been strongly driven by mathematical modelling, a fact widely recognised by those who contributed to the developments.

The enormous usefulness of mathematics in the natural sciences is something bordering on the mysterious and there is no rational explanation for it..... The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve.

EUGENE P. WIGNER, Communications in Pure and Applied Mathematics, 1960.

Feynman has expressed these ideas in his own inimitable style.

Every one of our laws is a purely mathematical statement. Why? I have not the slightest idea. It is impossible to explain honestly the beauties of the laws of nature in a way that people can feel, without their having some deep understanding of mathematics. I am sorry, but this seems to be the case.

RICHARD P. FEYNMAN, The Character of Physical Law, 1965.

Notwithstanding the central role of mathematical modelling in physics, teachers and textbook authors have tended to be rather reserved in communicating this to pupils and students. It is important to find ways of explaining to learners at all levels the importance of modelling as an indispensable tool in science and to be more forthcoming and explicit concerning the nature of the underlying model involved in each topic within introductory physics courses. These points were highlighted in a number of the plenary lectures at this conference, for example Mikelskis-Siefert (2006) and Lijnse (2006).

The use of the word 'law'

In the *Principia*, Newton enumerats the axioms of dynamics as Lex I, Lex II, etc. The term 'laws of nature' to describe the basic clockwork of the material universe is indeed effective. As physics developed, however, the term 'law' began to be used in a looser sense and these differences can be

found to be confusing by beginner students. There appears to be at least four distinct categories in the use of the word 'law' in introductory physics texts and emphasis on such distinctions can lead to greater clarity.

1. Fundamental 'laws of nature'

For example,

Newton's laws of motion, Law of universal gravitation Second law of thermodynamics Coulomb's law (Gauss' law), Ampère's law Planck/Einstein law etc.

2. Equations of state

For example,

'Ideal gas law' pV = nRT'Ohm's law' V = RI'Curie law' $\chi_m = C/T$ Constitutive equations in electromagnetism such as $D = \varepsilon E$, $B = \mu H$ etc.

3. Phenomenological mathematical models

For example,

'laws of friction' 'laws of collisions', i.e. a coefficient of restitution model (O'Sullivan, 2006) etc.

4. Basic general principles

For example,

'law of conservation of momentum' 'law of conservation of energy' Archimedes' principle etc.

In standard sequencing of material in most introductory physics courses, basic general principles like those listed are derived from other laws applied to specific contexts and are better entitled '<u>Principle</u> of conservation of momentum', etc.

Macroscopic versus microscopic models

Another common source of confusion for beginning learners arises when clear distinction is not made between models which are intrinsically microscopic and those which are essentially of a macroscopic nature. A case in point is where electric circuit theory is taught from the perspective of current flow (an analogy with fluid motion) but is *simultaneously* interpreted in terms of localized current carriers (electrons, ions, charged particles, holes, etc.). Of course, the 'fluid' involved in electric current flow does not have all of the properties of real fluids, such as viscosity. Herrmann et al (2006), at this conference, have suggested the name 'electronium' for this substance.

In another paper at this conference, Konicek and Mechlova (2006) pointed out the difficulties that arise in making the transition from the simple fluid model to models that can describe phenomena observed in superconducting materials. This emphasizes the need for models to be 'upward compatible' if easy transition of student learning between introductory and more advanced levels is to be facilitated. In the context of conduction in metals, therefore, it would seem prudent for students to be introduced in sequence to a hierarchy of appropriate models, for example,

fluid flow model \rightarrow free electron gas mode \rightarrow Drude model \rightarrow quantum mechanical model

It is important that, at each transition between models, the limits of the model being replaced be pointed out explicitly to students and, where possible, the replaced model should be interpreted within the new framework.

A more troubling example of mixing of models involves the teaching of surface tension. Common misconceptions in this area were highlighted by Kazachkov (Moore et al, 2005) at the GIREP 2005

seminar in Ljubljana. The underlying model here envisages a liquid surface as a stretched membrane, the surface tension of the material being defined as the tensile force per unit length or, equivalently, as the surface energy per unit area. Sources of confusion arise if this treatment is supplemented by reference to cohesive and adhesive intermolecular forces which, while not incorrect, cannot be related to the surface tension quantity in any easy way.

A very useful model for explaining everyday phenomena to pupils learning about physics for the first time is that of magnetic poles (or point magnetic charges). Surprisingly, this model is often neglected in elementary textbooks despite the ease with which it can be used to explain a wide range of common phenomena involving permanent magnets, such as the magnetic compass. Reasons for this neglect probably include the facts (i) that free magnetic monopoles do not exist and (ii) that magnetic phenomena can be 'more realistically' explained in terms of electric current loop; neither of these reasons would seem to be a particularly convincing argument for avoidance of the model..

Dvorak (2006) has shown how the observed voltage induced in a coil arising from the rotation of a nearby bar magnet can be explained in detail by modelling the magnet as a rotating magnetic dipole with equal and opposite point charges (poles). An equivalent explanation based on a model involving microscopic current loops would prove much more daunting for students. Similarly, the behavior of a magnetic compass is much easier for beginners to understand in terms of forces on two equal and opposite poles as distinct from torques on a very large number of microscopic current loops.

There is one further advantage to the use of the magnetic pole model in introductory courses. The model happens to be a rare example of a case where it can be introduced and used effectively while, *within the same course*, can be shown to be superseded by a more sophisticated model. Thus the nature of and limits to scientific models can be brought home to student in a clear and instructive way.

Ockham's razor

Given the absolutely central role it plays in scientific practice, it is extraordinary that Ockham's Razor gets so little mention in textbooks. The usual Latin form of the aphorism, traditionally attributed to the 13th century scholastic William of Ockham

Entia non sunt multiplicanda praeter necessitatem,

which may be translated as 'A multiplicity of concepts is not to be proposed without necessity', was originally formulated in the 17th century by John Ponse of Cork (Thorburn, 1918). The concept, however, is very much older. The following statement is said (Garrett, 2000) to be a translation of a declaration by Ptolemy in the 2nd century, writing in the context of changes in the solstices and equinoxes.

It is a good principle to explain the phenomena by the simplest hypotheses possible, insofar as there is nothing in the observations to provide a significant objection to such a procedure.

The injunction in the Razor to choose the simplest theory consistent with the observations is universally recognised as a central criterion for the acceptances of a scientific theory. By 'simplest' here is meant the avoidance of any redundant concepts or parameters. The postulation of quarks prior to the 1950s, for example, would clearly have been scientifically unacceptable.

It is precisely the constraint imposed by Ockham's Razor that distinguishes true science from parascience and other systems of thought purporting to explain the real world. For this reason alone, it is surely essential that all learners be made aware of its importance.

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Promoting the competence of mathematical modeling in physics lessons

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Presentation on GIREP-Conference 2006, Amsterdam

Abstract

Mathematics plays a twofold role for physics: first it allows for predicting results and outcomes of experiments; second, it provides a structure for the description of consistent theories.

The predictive power of mathematics for natural processes is in itself fascinating. But most pupils do not like mathematics in physics. However, in everyday life they encounter physical quantities where it may be important to know the numbers as well as the relations between different quantities. Therefore ways are sought to increase the eagerness of pupils to apply mathematics to physics phenomena. Making curious about numbers or showing relations between different processes might be a promising way. For this goal not only exact computations but also qualitative reasoning with aid of some numbers is crucial. Some examples are given.

Ways are discussed how to enhance the abilities of pupils in developing and evaluating mathematical models to physics problems. The use of graphical representations for a connection between experiment, measurement values, graphical representation and mathematical description is considered.

Introduction

The common overall goal of science education is that students learn to appreciate science and know the scientific method as part of the basis for life long learning. The students should gain insight into the scientific building and its internal structure. A quite important part of this building is the use of modeling and mathematics in science, especially in physics.

Most curricula expect at least that the students at the end of their school carreer are able to model physics phenomena. But modeling is by no means restricted to physics. Nowadays the whole of science and even beyond, e.g. to economical questions, cannot be thought of without mathematical modeling: it delivers predictions or provides theoretical models for explaining. The basic aspects of mathematical modeling in complex phenomena gain importance, especially as the computer power increases and more and more problems can be treated numerically in ever increasing precision. Since in physics the process of modeling is applied in physics as an important part of the scientific method. Successful modeling not only requires that students know the properties of a model but also have the ability to make predictions about definite values. This step needs mathematics and especially the ability of translating between the physics phenomena and the mathematical formulation. It seems to be the crucial difficulty and hence needs special attention in design of physics courses.

The role of mathematics in physics

There is a vast amount of literature on this topic. I only give one citation:

Since the times of Newton and Galilei the importance of mathematics for physical problems is undoubted. The application of mathematics tools to physics allowed for the step from philosophy of nature to modern science. The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve.

(Wigner)

The relation between mathematics and physics is not unambiguous: First of all mathematics is viewed as a tool in physics. It serves as a toolbox in providing functions, equations and rules for manipulations.

The main goal of physics is to make predictions, to determine values of physical quantities and eventually to verify whether the assumptions of an explanation might be correct. The efficient interplay of experiment and theory needs the mathematical description.

One could ask whether it could be possible at school to set aside the mathematics and rely only on a qualitative description. I would say in this connection that if we want to convey physics as a science and not as kind of knowledge about nature we need some mathematization.

Example: It can be observed that an accelerating body which for instance is falling, gets faster and faster. But this description does not give the exact dependence: some values of the fall have to be taken, compared and analysed, as e.g. demonstrated by Wagenschein, who uses strictly mathematical reasoning.

But the role of mathematics goes beyond this seemingly minor part as a tool. The example already hints to the next point:

Mathematics can provide the structures that help in analysing physical phenomena, seeing analogies and promoting physics research. As seen for instance with the Noether Theorems mathematical results can be of immense relevance for the fundamentals of physics. They reveal the inner structure and give hints for possible appearances.

It may be that the development of physics requires new mathematical tools and – on the other hand - that mathematics allows for predictions that have to be verified in the experiment.

Mathematics in some sense is the skeleton of physics: Sometimes qualitative explanations are only easily done, if the mathematical background is known. This structuring role is essential for theories and the derived models.

It may hence not be forgotten that the mathematical tools need interpretation in term of physics: The same mathematical structures may apply to several distinct physical phenomena: e.g. the equation for the electric potential, dependent on the charge distribution, the equation of heat transport and the stokes equation.

Mathematical concepts turn up in entirely unexpected connections. Moreover, they often permit an unexpectedly close and accurate description of the phenomena in these connections. Secondly, just because of this circumstance, and because we do not understand the reasons of their usefulness, we cannot know whether a theory formulated in terms of mathematical concepts is uniquely appropriate.(Wigner)

But also on a quite elementary level interpretation is necessary and consequences from the statements of mathematics have to be considered.

So the development of the relation between mathematics and physics may comprise the following steps:

- Physical phenomena are observed (surely on the basis of hypotheses or with a theory in mind) and they are analysed in a precise experiment or observations.
- They are described: What happens? What could be the relations: the more the less or vice versa ?
- An explanation is thought: Why does this happen?
- The influences of different parameters have to be separated and analysed, either experimental or theoretical. Idealisation and then mathematical modeling take place and give numerical predictions.
- These predictions can be tested and may lead to further research.
- The model has to be analysed and interpreted in all its derivations: Are all derivations consistent with the experiments or observations? Are further experiments necessary?

If looked at more sharply it becomes clear that most of these activities require reasoning and talking and communicating.⁴ The mathematics part is only at the end of a whole process and as stressed before needs again interpretation: What is the meaning of the structure? Has the equation implications not seen before (e.g. prediction of positron)? Is the model right in the limits (e.g. very high or very low temperature)?

What should pupils know about the role of mathematics in physics?

Mathematics is a fundamental part of the physics building. Hence the introduction to the techniques of mathematization is one important goal especially of physics education at school as the students have to learn to know the scientific method and different ways of gaining knowledge. There are several points to be conveyed:

• mathematics shows analogies between different processes: The formula for the Bremsweg of a braking car $s = \frac{v^2}{2a}$ as well as the formula for the maximal height of throwing $h = \frac{v^2}{2g}$ is treated in school. Students have to learn that the underlying physics is the same which in this case furthers the understanding. Several analogies occur in school physics e.g. for different forms of energy which

⁴It is told, that Feynman - to the astonishment of some guests - first discussed a matter before he went on to use equations or formulae or any other kind of mathematics
are defined in a similar manner: kinetic energy, magnetic energy of a soloid or the energy of a spring. Similar argumantes are used to derive the formulae. Therefore it becomes clear that mathematics only provides the structure. It has *per se* no meaning as mathematical constructs are at first abstract terms. They only get a meaning by interpretation.

- mathematics helps to recognize a structure or understand relations more precise.
- mathematics is more precise than qualitative descriptions. It states not only: the more the more, but specifies the dependence as linear, quadratic, fourth power, exponential,
- mathematics allows for predictions or estimates: the acceleration of a gymnast doing bar exercises, e.g. a big circle, or in a looping, the energy needed by a sportsman,

The aspect of doing estimates is in my view a very important one: The own questions of the students could be treated. They then have to do the modeling process on their own and translate it in known mathematical structures. I will come back to this point later.

What do students think about the role of mathematics in physics?

We did a small pilot study with a questionnaire in order to get some idea before broadening the sample (s. Fig.1). The results of this preliminary questionnaire give some first hints of the students' views (grade 11, 15 students).

They are mostly convinced that mathematics is an important tool of physics. But they seemingly don' think that with mathematics processes could be described. This answer would have to be analysed further with aid of interviews.⁵

The small experience of students with physics laws and a description by formula could also lead to the opinion that formula (or mathematics) could not show similarities. Nevertheless most pupils think they need mathematics to understand physics, but they do not agree that mathematics furthers understandig remarkably. However, it surely contributes to understanding. Here interviews would be needed to explore the meaning of these statements better, especially with respect to the meaning of "understanding physics"⁶.

This first glimpse on students opinions seems to show that some important aspects of the role of mathematics in physics are not acknowledged by the students. This may be caused by the big role formulas and rote learning play at school. It has to be taken into account, that most students only know very few formulae by heart beause they mainly use a formulary. Since the students' view is mostly imfluenced by the use of formula, we take a closer look in the students' view about the role formulae in physics (lessons).



Fig. 1: Mean value of agreement in a class (grade 11) of 15 students. (5: I agree totally, 1: I disagree)

⁵Furthermore it would be important to learn to know the teachers conceptions and goals about mathematics in physics.

⁶It seems that some students learn formula by rote and rely on them in exams because they have the feeling not to understand the physics behind.

The role of formula

The students do not mean that they understand a subject better by learning a formula. But it seems, that formulae might give the pupils the certainty and a fixed basis on which to argue.



Formulae and Understanding in Physics Lessons

Fig. 2: Mean value of agreement to these statemants concerning the role of formulae in physics lessons in aclass (grade 11) of 15 students. (5: I agree totally, 1: I disagree)

This is supported by the statement: "With formula I understand physics better" where students seem to agree slightly. However, they think explanations won't be sufficient to physics understanding. But throughout the students agree that formulae are an important part of physics.

If they are asked, whether ist is difficult to find the right formula in a given problem, they answer undecided. Mostly the exams or tests are constructed in such a way, that only a few formula are needed and can be guessed from the general subject and the lessons. Also the tabulary helps a lot. Nearly all students use it regularly and very often.

There are some deficiencies in the view of students on the role of mathematics which seem to mirror the emphasis laid in school on calculation. If however the goal is insight of students in the scientific method (s.e.g. Hestenes 1992) and the ability of applying the physics content in everyday life then the emphasis in school lessons has to be shifted to modeling which also broadens the accessible subjects in school.

Which proposals could be made to enhance the ability of modeling?

Proposals for promoting the modeling competence

The ability of modeling requires in the first step that the students can recognize the connections between different physical quantities and concepts and their structure and that they have understood their dependencies. It may not be forgotten that for the application of mathematics in physics the semantics is most important. Therefore the road from observing physics phenomena to mathematical modeling has to be planned carefully and has to be gone slowly and purposefully.

1. Clarifying the way of gaining insight

Many problems students have mainly consist in translating between the physical objects with their relations and the mathematical formalism. To achieve this ability a careful path from the everyday experience to the formula has to be observed. Five steps show important for bridging the gap between the "world of objects" and the "world of formulas":

- 1. Activation of own experiences or experiments
- 2. Qualitative formulation of relations
- 3. semi-quantitative formulation, together with a graphical representation
- 4. Introduction of formula
- 5. Re-interpretation of formula and hints to analogies

Steps 2 and 3 are most important for insight into the process of modeling. They form the ladder from daily life to the abstraction in mathematical formulation. The main goal is the understanding of the process leading to a formula. For this, especially step 5 is essential for anchoring the meaning of a formula, but too often it is neglected. Students tend to simple learn the characters of a formula, hardly remember their meaning and – not interpreting it in their own words – they may just interchange the different chracters: the formula is useless and meaningless to them. But the presupposition for recognising analogies or similarities in physics consists in understanding the physics background, seeing the dynamics and then making purposefully the transition to the mathematical representation.

2. Making curious about mathematics in physics

In order to overcome the common disliking of computational tasks in physics I suggest to bring the students to ask about definite values of physical quantities. Suitable methods – also for furthering physics understanding - would be:

- problems that separate between the task of analysing the physics contents and the computation of numerical values
- differing explanations or hypotheses of the same phenomenon that only can be decided by some computation
- amazing questions that stimulate the students for wanting to know numerical results

It is a difficult task of physics education research to develop kinds of problems that further insight into the structure of physics as well as the ability to translate in simple cases physics problems into a mathematical representation by the process of modeling.

An important aspect herewith is idealisation and simplification. So in modeling real processes students have to recognize which parameters are important and which may safely be neglected (Wells, Hestenes, 1995). But sometimes students do not know when they have to look carefully and when they have to neglect a parameter regarded as important. The reduction to a level appropriate for school is quite important and one of the difficulties in interesting problems.

In simple cases students can do the idealization part of the task with surprising confidence: They are aware (e.g. in mechanics) that often friction is neglected, that a body is regarded as a mass point and so on. Once the students have grasped the significance and characteristics of models (s.e.g. Mikelskis-Seifert, 2005), this insight should be used to open up new subjects for students in physics lessons with a twofold goal: making physics interesting and relevant for daily life and furthering their abilities and selfconfidence. The possibility of treating interesting problems not only in mechanics but also in other subjects as thermodynamics might enhance the motivation or interest also with girls. The training of modeling should be used to treat problems not only with qualitative reasoning - which is extremely important - but in some cases to finish the reasoning by concrete calculations which give the students the certainty to be right, especially with estimates for everyday phenomena.

Examples for simple tasks of mathematical modeling

I will explain two examples in order to make clear that the mathematical formulation is only the end of the modeling process.

Example 1 (Grade 11): Which acceleration an athlete doing a grand circle at the horizontal bar has to endure in his wrists?

Unfolding: How can the man rotate? He uses the vibrations of the reck, and moves his body (stretching and bowing) in order to sustain the movement.

Reasoning and reduction: The vibrations of the bar are too difficult, the bodie's inner movement also, the mass is thought to be accumulated in the center of body, the distance to the bar ist estimated by approximation. Hence the following assumptions have to be made:

- The bar is assumed rigid.
- The friction is neglected.
- The mass is concentrated in the middle of the body.

These three simplifications are sufficient to do the calculation and the result gives δg , where g is the earth acceleration.

As simple as this example is, the students could go mainly by themselves the way from everyday life to the physics and the subsequent computation. A training of the students in this spirit is important (Hestenes, 1992), It should be used not only in mechanics but also e.g. in thermodynamics, from which the following example comes.

Example 2 (Grade 8) How much nutrition needs a cyclist on a tour de France?

Unfolding: In this complex problem many aspects play a role: the mountain climbing where potential energy is involved, the efficiency of the human body as an "engine" (about 25%-30%), the velocity (or power) a cyclist can sustain. the air resistance and the efficiency of the bicycle. Besides these physical aspects it can be asked which sorts of drinking and food are appropriate, which leads to interdisciplinary questions.

Reasoning and reduacion: It has to be discussed which of all these parameters are important and which could be safely neglected. Hence the students have to calculate or estimate the different energy consuming parts (e.g. the potential energy of climbing) and to gather information , e.g. about air resistance during cycling and its dependence on the velocity and the rolling resistance.

Evaluation: The results will be compared to each other and to the real need of a cyclist. Then it has to be discussed which parameters have the biggest influence on the energy need of a cyclist and why. Further derivations can be made for similar situations in daily life.

The process of modeling needs support from different sources. One important tool is the use of graphs and diagrams in many variations. (Wells 1995)

2. Diagrams and physics

The use of mathematics in a broad sense starts with taking values in experiments, goes to drawing diagrams, interpreting them and in the end deriving a mathematical formulation and interpreting it again. This chain of activitites is the first step towards mathematical modeling.

In general, graphical representations are easy accessible for students. They train them already early in school, beginning in primary school on an elementary basis. In grade 6 they should be able to put values into a coordinate system. The crucial point is the interpretation of the graphical representation in physics connection. Herewith several points are to be considered:

- Description with language requires more knowledge about the interdependencies than simply stating a formula.
- Drawing a graph requires to identify the independent and dependent variables.

Use of both types of representation together are the ingrediences for grasping the structure of content. Diagrams visualize dependencies and as an iconic representation of (experimental) results use a second way to memory besides the formulation by language or mathmatics.

So it is most important to stress the interpretation of a diagram and formulate its meaning in the students' own words.

3. From a concept map to a mathematical model

At school often only very simplified models are treated, for instance in neglecting friction or other parameters. These often do not mirror the experiences of students. The availability of modern computers and simulation software, however, enables students to develop and analyse more complex models that could not be treated analytically. Nevertheless, students need experience in changing between the "world of objects" and the "world of formulas". A concept map could be of help. In the first step the students have to clarify the structure of the discussed topic, be it for instance electricity, mechanics or atomic physics. This requires that students possess a stable knowledge and have insight into the structure of the subject which can be worked out with aid of a concept map. It has shown of advance if the students work together in pairs: there is opportunity to discuss the content and clarify it in this way. The sorting out and structuring can happen using common language and physics terms. Examining the relations then results in establishing the mathematical formulation which has to be translated into formulas and perhaps an algorithm. Below the example of free fall with friction is indicated.



In the following I will describe a proposal for developing the competence in mathematical modeling in more detail (see also Hestenes 1992, Wells 1995).

Proposal

- A problem is to be posed according to the knowledge of the students taking into account the question of motivation (situated learning, context oriented, everyday relevance, fascinating question)
- The students enter into qualitative reasoning with hypotheses and making explicit the theoretical backgraound: What will happen, why will this happen?
- They enter physical reasoning: which effects play a role, which parameters are important, which could or should be neglected, because they only have a small influence or otherwise the problem would be to complicated.
- After this idealisation process a discussion is necessary: how precise can the result be? How can the expected result be tested by further information or an experiment? The physical process has to be translated with aid of laws into mathematics in a wider sense by drawing a diagram or deriving a formula.
- Only in the last step by computing, inserting numbers and calculation a testable result is derived. This has again to be interpreted by discussing special cases, errors or deviations from actual values. The limits of the model are analysed.

Mathematics and physics at school

In most curricula it is expected that the students are able to solve problems and to apply physics knowledge to everyday phenomena. Besides making hypotheses, planning and doing experiments this comprises the adequate use of mathematical methods. In a similar sense as explained above also in school mathematics is regarded as a tool for physics. But students have to cope with differences in goals and perspectives between mathematics and physics which causes additional difficulties.

Before discussing possible steps to be taken for bridging the gap between physics and mathematics I will analyse the necessary mathematical tools at school. In the case of mathematics and physics there are some pitfalls because of different semantics that often are not properly addressed:

Mathematics	Physics				
Numbers	Numbers with units				
Fraction	Relation				
Function in an abstract sense	Functional dependencies				

Differences in terms:

Mathematics	Physics
Geometrical objects	Symbolic representations of physical units
Differentiation	Rate of change
Integration	Integration

Mathematical tools at school

A basic understanding of certain features is substantial for physics at school:

- *Functions*: They are most important because they are used for describing dependencies between physical quantities. Examples are the accelerated motion or the radioactive decay.
- *Integration*: This tool is at least in its most simple form used for modeling the accumulation of physical quantitites. The most used example is work as the effect of force along a line, summing up along a distance or the derivation of the law for accelerated motion by summing up in time.
- *Differentiation*: One of the most important features in modeling consists in describing the rate of change of a physical quantity in time or space. The earliest example pupils encounter is the velocity.
- *Geometry / vectors*: Geometrical properties are often needed for analysing the motions of objects in space, especially in adding forces or velocities, superposition of motions planetary motions and optics, e.g. theorem of intersecting lines, too.
- *Algebra*. Students need algebraic abilities for manipulating formulas on different levels and in different contexts.

Often the problem is mentioned that the pupils do not yet know the appropriate mathematical tools for treating the physics contents. Partly this may be a problem of synchoronizing the lessons in mathematics and physics, partly it is a principal problem because of the different goals and views in those two subjects.

But with some compromise both subjects may help each other. I give some examples from the saxonian curriculum in Germany. This table shows that although the term of "function" in the mathematics content is not treated before grade 8, proportionalities are already used in grade 6. Proportionalities are examples of linear functions that can be taught without fully referring to the mathematical definition of a function. But nevertheless the graphical representation of a proportionality is a very important tool in recognizing linear dependencies as for instance in Ohm's law or the time-distance law of uniform motion. (Nearly) all functions can be represented graphically which has two advantages:

- The graphics build the bridge between the experimentally measured values and the abstract formula.
- The graphics serve as a visualization, that means an additional help for memory

Graphics serve as a representation of the qualitative behaviour of physical objects.

Grade	Mathematics	Physics
6	proportionalities	Velocity, density
7	rational numbers	Ohm's Law
8	different types of functions	Meaning of parameters
9	quadratic functions	Laws of accelerated motion
10	trigonometric functions	Periodic motions, oscillations

Conclusion

Developing competencies in scientific thinking is the main task of physics education. The knowledge of mathematical tools is an important part. To achieve that students are able to model phenomena from

daily life they need training with suitable problems. Therewith the balance has to be found between the necessary guidance and the students' self directed learning and inquiring. The guidance consists in giving the students a direction how to proceed, which steps to take; the free inquiry requires that the students learn to structure their knowledge and to findsuitable idealizations by themselves. So a task of physics education research is the development of suitable problems and learning environments in order to engage the students in appropriate activities. The connection of phenomena and formulae should be trained more explicitly.

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Teaching Modeling Concepts in an Undergraduate Electronics Laboratory

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Introduction

Models of physical phenomena and systems are an important part of physics culture. Accordingly, students are introduced to models early on in their education. For example, students taking an introductory physics course learn about the Bohr model of the atom and ideal gas model. They are alerted to the limitations of these models but they have very little opportunity to explore the limitations. An undergraduate laboratory for teaching electronics principles in conjunction with performing physics experiments offers an opportunity for conveying modeling practices to students. In the spirit of experimental physics a student can systematically explore the behavior of such things as transistors and operational amplifiers without knowing the specifics of how the devices work. Models can be deduced and used to predict the behavior of the devices in circuits. Circuits employing the models can then be built to assist recording experimental measurements. Theoretical models can then be used in the analysis of the measurements. We describe here a few examples taken from a sophomore laboratory in electronic instrumentation.

Thevenin's Theorem

Modeling something enclosed in a fictitious "black box" is a bit of physics lore. In electronics there is pedagogical merit to actually enclose some element or circuit in a box with selected wires extending from the box. From electrical measurements on the wires one tries to model what is in the box. To illustrate, consider a source of emf such as a battery (Fig. 1). When a source of emf is included in a circuit, both the emf (\mathcal{E}) and internal resistance (R) need to be known. The emf can be determined from a measurement of the open-circuit voltage between A and B and the internal resistance can be determined by dividing the emf with a measurement of the short circuit current. Suppose now that a circuit of emfs and resistors is placed in a box with two leads from two points in the circuit (Fig. 2). Measuring the open-circuit voltage suggests there is a source of emf in the box. Assuming this to be correct and proceeding to determine \mathcal{E} and r one finds that for circuit analysis the circuit in the box can be modeled as a source of emf. Approaching this powerful analytical tool, commonly called Thevenin's Theorem, with experimental modeling ideas helps to remove much of the mystery of the Theorem.





Figure 2: Example of a circuit contained in a "black box."

Operational Amplifier

Students taking our electronics instrumentation course would have had a full year of a comprehensive calculus-based introductory physics course. They would be taught the important physics in Kirchhoff's rules and would have applied the rules to a number of circuits involving resistors and batteries. Early on in the course before students have been taught the details of transistors and operational amplifiers we use modeling techniques to get them involved in building circuits and recording measurements. The first laboratory exercise emphasizes the general validity of Kirchhoff's rules and how an operational amplifier can be modeled from experimental measurements.

Students approach the experimental "black box" setup shown in Figure 3 knowing nothing about an operational amplifier and having little familiarity with the idea of an amplifier. Given a voltmeter, they are instructed to sum the voltages in loops of their choosing. Two loops of particular interest are

$$V_i + V_d + V_r = 0$$
 and

 $\mathbf{V}_{0}+\mathbf{V}_{r}+\mathbf{V}_{R}=\mathbf{0}.$

Besides verifying Kirchhoff's loop rule, they discover for a wide range of resistances that 1. the voltage (V_d) is essentially zero between the terminals of the operational amplifier and 2. the current entering the operational amplifier is essentially zero. Constructing a model with $V_d = 0$ and no current into the operational amplifier it follows that $V_i - Ir = 0$ and $V_o + I(r + R) = 0$. Eliminating the current (I) from these two equations yields $V_o = \left(1 + \frac{R}{r}\right) V_i$ implying that a voltage (V_i) can be scaled to a different voltage (V_o) simply by choosing the

ratio of the two resistances. Students find this model to be valid but only so long as V_0 does not exceed the voltages used to power the operational amplifier. Alas, they learn that this model, like all models, has limitations.



Figure 3: Setup for probing the electrical characteristics of an operational amplifier.

It is common to record measurements from experimental apparatus with a computerized data acquisition system employing an analog-to-digital converter (ADC) requiring a voltage input. The voltage produced by a sensor such as a thermocouple can be scaled to accommodate an ADC using the arrangement shown in Fig. 3. If a sensor produces a current or resistance the current or resistance must be related to a voltage to accommodate an ADC. A circuit performing the desired function is easily fashioned using an operational amplifier and the simple model at hand. For example, suppose that a student is interested in producing an electronic thermometer. A thermistor producing a resistance related to temperature is a useful sensor. If a constant current can be maintained in the thermistor, the voltage across the thermistor is proportional to the resistance. Referring to Fig. 3 it is easy to see that to the extent that $V_d = 0$ and V_i is constant, the current in resistor r is constant. A useful electronic thermometer evolves from the circuit in Fig. 3 simply by using a thermistor for r and measuring the voltage across the thermistor. When used as a temperature sensor a

thermistor is usually modeled as $R = R_0 e^{B/T}$ where R_0 and B are constants and T is the kelvin temperature. The voltage across a thermistor has the same exponential behavior if the current in the thermistor is constant. The log of the voltage as a function of temperature is described by

 $log(V) = log(V_0) + B/T$ showing that log(V) is a linear function of 1/T. Measurements of log(V) and 1/T using the circuit in Figure 3 with r being a thermistor are displayed in Fig. 4. The quality of the results supports the models of the operational amplifier and thermistor.



Figure 4: Temperature-voltage characteristics of a thermistor.

Transistor

Solid state diodes have many uses as an electronic switch modeled as a two-terminal nonlinear device whose resistance is zero when the anode voltage is positive relative to the cathode and infinite when the polarities are reversed. A student can verify this behavior using an ohmmeter. Ask a student to model a bipolar junction transistor using ohmmeter measurements and he/she will conclude that an NPN transistor appears to be two diodes with the anodes connected together (Figure 5). Now ask "suppose you want to further the investigation by measuring voltages and currents." At first, the exercise seems formidable because there are three voltages between pairs of the terminals and three currents in the connections to the terminals (Figure 6). Fortunately, Kirchhoff's rules allow you to reduce the number of variables from six to four. Still, this exercise, like investigating the thermodynamic properties of a gas, is tedious unless done in a systematic fashion. Reminding students that the ideal gas equation evolved from measurements such as pressure and volume keeping the amount of gas and temperature constant, a similar investigation is in order for the transistor. With some foresight, it is suggested to measure the collector-emitter voltage and collector current keeping the base current constant. Measurements taken with a National Instruments data acquisition system accessed with LabVIEW are presented in Figure 7. Even if a student knows little about the physics of an NPN transistor they quickly grasp the idea that a change in base current produces a much larger change in collector current. Plotting collector current

versus base current the student finds that the data are modeled very well by $I_c = 80 I_b$. Using this model, the student can now begin to analyze circuits containing a bipolar junction transistor.





Figure 5: Diode model of a transistor.





Figure 7: Electrical characteristics of an NPN transistor.

Damped Physical Pendulum

A familiar experimental setup for recording the angular position of a damped physical pendulum uses the shaft of a rotational-type variable resistor as a pivot

(Fig. 8)¹⁻³. Damping is due mostly to the pivot in this arrangement. The variable resistor serves as a transducer relating angular position to resistance. Generally, the resistance is related to a voltage using a voltage divider. A set of measurements is shown in Fig. 9^4 .



Figure 8: Familiar setup for studying the motion of a physical pendulum.

Figure 9: Angular position of a pendulum as a function of time

The analysis of a damped physical pendulum assuming that the damping torque is proportional to velocity is usually discussed in a calculus-based physics text^{5,6}. Using Newton's second law and the small angle approximation for $\sin\Theta$, the equation of motion for the pendulum can be written as

$$\frac{d^2\Theta}{dt^2} + \frac{2}{\tau} \frac{d\Theta}{dt} + \omega^2 \Theta = 0$$

where
$$\omega = \sqrt{\frac{mgx}{I}}.$$

The total mass of the pendulum is m, g is the acceleration due to the gravitational force, x is the distance from the center of gravity to the axis of rotation, I is the moment of inertia of the pendulum about the axis of rotation, and τ is the damping constant. The differential equation is solved by

$$\Theta = \Theta_0 e^{-t/\tau} \cos \omega_1 t$$
.

where Θ_0 is the maximum angular displacement and $\omega_1 = \omega \sqrt{1 - \frac{1}{\omega^2 \pi^2}}$

Students are familiar with this model and they are inclined to apply it to the pendulum attached to the variable resistor. Although the model describes the data reasonably well for a number of cycles (Fig. 10) it fails noticeably near the end of the lifetime of the pendulum.



Figure 10: Comparison of the velocitydependent torque model with experimental data.



Examining the data, it is obvious that the damping is more linear than exponential. If one is interested only in an empirical model to describe the data then linear damping describes the results quite well. A student in our laboratory was not satisfied with empiricism and he developed a model assuming that the damping torque is constant. Solving the differential equation of motion for the pendulum for a constant damping torque provides a bit of a challenge because the algebraic sign of the damping torque does not change automatically

when the velocity changes direction. The student modeled the frictional torque as $d \operatorname{sgn}\left(\frac{d\Theta}{dt}\right)$, where *d* is a friction parameter and sgn (x) is a function defined as sgn (x) = 1 for x > 0, sgn (x) = 0 for x = 0, and sgn (x) = -1 for x < 0. In terms of the constant friction function, the equation of motion can be written

$$\frac{\mathrm{d}^2\Theta}{\mathrm{d}t^2} + \omega^2\Theta = -d\,\mathrm{sgn}\left(\frac{\mathrm{d}\Theta}{\mathrm{d}t}\right).$$

The details of the solution of this equation can be found in reference 7. Figure 11 shows the results of applying this model to the experimental data. Clearly, the model describes the experimental data quite well.

Extending the results of a model beyond the limits of its validity is always risky. If one were to apply the constant friction model beyond the time when the pendulum stops oscillating the numerical results suggest that the pendulum begins to oscillate with increasing amplitude.

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Modelling the Electrolocation of the Weak Electric Fish

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Abstract

As a biological application of physics we discuss the physical relevance of the weak electric fish. We show how it can be used in a basic physics teaching situation utilizing both measurements in an aquarium and computer modelling and simulation. The learning outcome concerns concepts of electric force, field and potential as well as electric material properties. The application serves the purpose of widening the field of physics and so increasing the learning motivations.

Introduction

The elephant nose fish uses weak electric forces to sense its environment. Its natural inhabitance is in muddy rivers of Africa where the use of the vision sense is of limited importance. Using specifically developed muscle cells it makes itself to an approximate electric dipole and locates and identifies foreign objects through electric interactions. These objects are originally electrically neutral but become electrified through the external influence produced by the fish. Since muscles are utilised the electric potential generated will become pulse shaped, maximum 20-30 pulses per second with a duration of 1-2 ms. Close to the fish the potential generated is a few mV.

Along its body, with highest concentration around the head, there are small pits where hair cells are influenced by the electric interaction. By using information from all cells, the fish is able to locate and identify its environment for the purpose of orientation, defense and feeding.

A different class of species of the weak electric fish generates a continuous wave of the potential, resulting in an electromagnetic wave with a frequency of around 300 Hz. This wave is also used for communication, in particular between the sexes.

The understanding of the electrolocation sense is of prime importance in life sciences, connecting to questions concerning evolution and ecology. An important characteristic of this sense, which is very rare in nature, is that the fish generates its own probe to sense the environment. Together with bats and dolphins, which use ultrasound in a similar manner, they form a unique group of species.

The weak electric elephant nose fish is simulated utilizing the Femlab electromagnetic software package (ref 1). We are then able to investigate some important properties of the electrolocation sense such as the effect from the shape and electric properties of a foreign object as well as its distance dependence. Also, we might investigate the importance of the surrounding medium, exploring the fact that this sense has been evolved for water living animals only.

It is quite feasable to keep an elephant nose fish in an aquarium, being aware though of its extreme sensitivity. Measurements of the electric potential can easily be performed and provide input to the simulation.

FIG. 1 Elephant nose fish in an aquarium. Its length is around 20 cm.



Model definition

Since the time variations of the electrical signals for both classes of fish (pulse and wave) are relatively slow we may approximate the problem as electrostatic, i.e. ignoring magnetic effects. In our first approximation we consider the situation to be plane symmetric, utilizing the 2-dimensional problem solver of Femlab.

From measurements we find that the elephant nose fish can be approximated by an electric dipole. Although in reality its electric generator organ consists of several series coupled flat muscle cells, equivalent to a series capacitor, by simplicity we approximate the fish as an electric dipole (fig. 2). The charge density of the diploes is adjusted in order to reconstruct the measured potential pattern around the fish. Then we place objects of different shapes and electric properties at different distances in its neighbourhood and check for changes in the potential on the skin where its electroreceptors are placed in reality.

The sensitivity of the electroreceptors is believed to be of the order of 1 μ V (ref 2). Using this information it is possible to conclude about the resolution of the sense.

FIG. 2 Subdomain definitions, units in meters. The dipoles corresponds to the electric generator organs, in reality a series of muscle cells. To achieve the proper field strength the charge density is set to 10^{-7} C/m³



The fish is placed in a surrounding box, which we might imagine as the aquarium borders. Here the potential is assumed to be zero, being at far distance from the fish.

The Femlab program solves for the potential which obeys the Poisson's equation

$$\Delta V = \frac{\rho_0}{\varepsilon_r \varepsilon_0}$$

where ρ_0 is the charge volume density, ϵ_0 is the electric permeability and ϵ_r is the electric relative permittivity, also called dielectric constant. The electric field and displacement are then obtained through

$$\overline{E} = -\nabla V$$

 $\overline{D} = \varepsilon_r \varepsilon_0 \overline{E}$

Results and discussion

Figure 3 shows the result of a calculation with a foreign object included, with a relative permittivity of 4. We observe the typical dipole pattern of the field lines, the "distorsion" of the dipole field close to the object and the continuity conditions at the interfaces between different media. By comparing with a calculation done without the foreign object we observe a change in potential of a few microvolts, i.e. in the range of the fish's sensitivity, see figure 4.

FIG. 3 Result of the calculation. The potential is illustrated with colours with scale to the right. The electric field is visualized with arrows and flowlines. The length of the arrow is proportional to the strength of the field. Along the head a line is defined where the potential is plotted, see below.



FIG. 4 Potential along the line marked in figure 3 with object (left figure) and without object (right figure). We observe a small but detectable difference.



Pedagogical Aspects

Traditionally, physics is predominantly applied to technology. Presumably this is connected to the male dominance of the subject. The low and decreasing interest for physics in the world community might be related to this unnecessary concentration of a single aspect of the subject. Widening its application towards e.g. biology, as in this work, serves the purpose to attract people with interests in life other than technology. Since the interest for the science of living systems is widely spread it might result in an increasing attraction for physics in general. Specifically, one would hope to adjust the gender unbalance of physics, which is one important symptom of a basic system error of the subject. The biological applications help to alter the reputation from dull and abstract to a living and modern subject. It makes physics alive.

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"My fingers are cold", modelling thermal phenomena in the hand

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Introduction

Teachings of natural sciences have changed recently in our primary schools. New school subject was introduced which connects physical, chemical, and biological topics and is called Science. A nice example of connecting theme is conservation of body temperature. We did not want to present this subject only from theoretical point of view therefore we prepared a set of practical models. The simple hand fingers and palm model was evolved and improved during the project as we investigated how different external circumstances affect the temperature. At the end we measured temperature of real fingers and palm and compared results with the model.

We were additionally motivated to carry out our planned activities by the news from our alpinists who were climbing mountains in Himalaya at that time. Frostbites due to extremely low temperatures are frequent events on such expeditions. Usually fingers and toes suffer the most, but noses and ears follow immediately

Activities

We started with measurements on a simple model. The volume of a human hand was measured first. We found out that the volume of a typical hand was about 300 ml. We took a latex glove; we filled it with 300 ml of water at 37°C and put it on a table. Another two latex gloves were filled with the same amount of water at the same temperature, but dressed additionally in wool gloves, one the four fingers kept together in the same pocket of the glove and the other with one pocket for each finger. After 20 minutes, we touched the gloves and felt the difference. The naked latex glove was cooled down the most, the woollen glove with fingers was warmer and the woollen glove without separate finger pockets was the warmest. To investigate which external circumstances influence the measurements, we changed the surface on which the gloves were lying. It was obvious that the influence of the surface was strong. Such simple models are suitable for younger

pupils, especially if the temperature of the water in a glove is much different than the temperature of surrounding air (if experiments are performed outside during winter).

Temperature was measured with IR thermometer. We found out that measurements were not as precise as we hoped for. The thermometer grasps radiation from a wide angle and not only from tiny fingers therefore were temperatures of fingers not determined very accurately. Palm temperature could be measured more precisely because of its larger surface.

To exclude the influence of the surface the gloves were hanged from a rope. Immediately we observed that convection in water becomes important. Warm water went up and cold water went down into fingers. Temperature of the fingers which were positioned below the palm was therefore additionally lower than temperature of the palm due to the water convection.

Figure1. Measuring the temperature.

Next, the gloves were put onto the paper cylinders which were perforated to enable the air convection around the glove. For measuring temperature the IR thermometer was used therefore results were a bit imprecise but nevertheless they supply an approximate picture how the temperature of the fingers and the palm changes with time.

Time (min)	0	2	4	10	15	20
model palm (T[°C])	40	39	37	33	30	28
model fingers (T[°C])	40	35	30	29	25	23

Table1. Temperature of fingers and palm on the model changes with time.

Differences in temperatures are large enough to conclude that for our model of the human hand the temperature of the fingers is lower then the temperature of the palm (the temperature of air was 3°C).

Measurements of the temperature of the human hand

Temperature of the fingers and the palm was measured outside when the air temperature was 3°C with the IR thermometer.

Time (min)	0	10	15	20
human palm T[°C]	36	24	22	20
human fingers T[°C]	34	21	16	10

Table2. Temperature of fingers and palm (human) changes with time.

After standing twenty minutes in the cold outside the temperature of my palm was 22°C and the temperature of my fingers was 10°C. Measurements were approximate since it is important how fingers were positioned during these 20 minutes. If they are together the temperature of the middle finger is not the same as temperature of the little finger or the thumb. If fingers are kept apart the measurements are influenced by the surrounding (IR thermometer grasps radiation from a wide angle). However measured temperatures show that fingers get cold sooner then the palm.

Afterwards I warmed my hands above the heater and measured how the temperature of my fingers and palm was changing again. As before I found out that the temperature of the fingers changes faster then the temperature of the palm.

We have evolved our project further. We have asked students of Physics and Technology at our department at Faculty if they would accomplish more precise measurements of finger and palm temperature with NTC thermistor connected to a computer, which automatically records measurement data. To protect a vulnerable sensor we have measured temperature between the latex gloves, which were put onto students' hands, and their skin. Students put their hands with latex gloves and temperature sensors into the mixture of snow and water (which temperature was close to 0°C) and keep them there until they could endure (but not too long, to avoid frostbites). They acquitted themselves well. Here I present one set of recorded measurements. Time interval between subsequent data is 4 seconds.

Time (sec)	0	4	8	12	16	20	24	28	32	36	40
human palm T[°C]	35.2	33	31	29.5	28.4	27.6	26.9	26.3	25.9	25.5	25.2
human fingers T[°C]	30.2	25.9	22.3	20.1	18.7	17.9	17.4	17.0	16.6	16.3	16.1

Table2. Measurements of fingers and palm (human) after submerging in cold water with NTC thermistor.

After 40 seconds fingers cooled down for approximately 14°C and palms for 10°C.

We were also interested how temperature of fingers and palm changes when the hand is sunk into the hot water with temperature around 45°C. Here are results.

human palm T[°C]	32.8	34.1	35.6	36.4	36.9	37.2	37.4	37.7	37.9	38.1	38.3
human fingers TI°Cl	22.9	26.2	28.5	29.7	30.6	31.2	31.6	32.0	32.2	32.5	32.7

Table3.: Measurements of fingers and palm (human) after submerging in cold water with NTC thermistor in 4 seconds intervals.

Computer recorded temperature in time intervals of 0.20 seconds. It was interesting to find out that differences emerged out between individuals. Initial temperatures of fingers and palms of students A, B, ... H are presented in the following table, to compare.

T[°C]	А	В	С	D	E	F	G	Н
human palm T[°C]	32.8	35.2	35.2	32.7	29	25	25	29.3
Human fingers T[°C]	22.9	30.2	30.2	28	23	24	21	25.5

Table4.: Initial temperatures of fingers of student's hands.

Other observations and explanations, which can be performed and given during the experiment:

It should be explained to pupils how the organism spontaneously responses to a temperature change. Of course organism response can not be observed with models. What do we could observe and talk about?

When it is cold:

- 1. Hairs stay on end due to contraction of muscles which lie in the skin. People experience these as creeps. Some animals have hairy fur coat which protects them against coldness with an isolative layer of air which is caught in fur coat. It is especially interesting to discuss about animals that live in Polar Regions (penguins, polar bears). People do not have such an excellent thermo protection which is why we need clothes.
- 2. Thin blood vessels in the upper skin layer contract, therefore less blood reaches the skin the amount of heat lost from the core is reduced. This phenomenon can be seen clearly at noses, ears, fingers, which jut out from the bulk human body. These parts of the body have large surfaces with respect to their volumes and consequently they cool faster.
- 3. Processes of metabolism intensify. Due to the coldness the amounts of hormone thyroid in the blood increase. The thyroid hormone reaches all the cells of the body and increases their metabolic activity which increases heat production. When it is cold around us, we shiver. Shivering with cold is spontaneous and stimulates metabolism in muscles.
- 4. If a person is exposed to low temperatures for too long, brains suffer first, then metabolism is reduced and consequently less heat is produced to warm the body. When the internal temperatures falls below 25°C, death is imminent.

When it is hot:

1. Hairs lay down by the skin.

- 2. Thin blood vessels in the surface layers of the skin broaden and flow of the blood through the skin increases.
- 3. Metabolism processes reduce and the heat production is smaller.
- 4. The body perspiration gets more intense. Cooling down with perspiration is the only possible way of cooling when the temperature in surrounding is higher then the body temperature.

Conclusions:

We used several methods for measuring temperature. We have shown how to conduct an experiment when starting with a simple model and how to evolve it. We used measuring equipment that is widely available (IR thermometer) and connected to computer. We have shown that fingers cool faster then the palm (both on a hand model and on a real human hand) and connected this finding with examples of biological response to cold temperatures.

For more precise measurements the temperature of all hands should be the same. In this case, we can also measure the difference between cooling of small and big hands and the difference between hands of children and adults of both genders. A vulnerable NTC thermistor measured temperature within the glove as it can't be used in water. In the meantime, even better thermometers became available. We are planning a new experiment where different glove sizes will be compared in order to understand the effect of volume–surface ratio of the hand.

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Multiple Perspectives of Thinking Journey as Helping the Learners of Physics Using Computerized Model

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Abstract

Thinking Journey (TJ) approach suggests the way to improve learning physical concepts in introductory physics teaching. The approach suggests explicit determination of the learner's perspective and its frequent change, instead of the presentation from a unique perspective, as it is usual in teaching practice. Changing perspectives allows students to overcome their natural egocentric view, which is important in learning physics in general and astrophysical concepts, in particular. We exemplify the method of TJ mediation in regular teaching using a computerized model of the Earth and the Moon (day-night cycle) and summarize the features of the method making it effective in conceptual learning of physics. We mention students' merits of cognitive nature caused by the method of mediation in teaching which may improve the lack of students' success in a regular as well as in the constructivist based teaching of physics.

Introduction

The advantages of the recently suggested mode of teaching physics through a Thinking Journey (TJ) (Schur 1999; Schur et al. 2002, Schur & Galili 2006) can be illustrated when this approach is introduced together with using a computerized tutorial modeling the solar system for the purpose of learning astronomy (Yair et al. 2001, 2003). In the regular use of the computerized tutorial for teaching astronomy students are informed about celestial objects of the solar system, especially about planets, the Earth and the Moon. The subjects are described in a unified template: general information, size, composition, orbit, weather, historical notes, etc.

Unlike the common teaching presenting certain scientific content, TJ approach suggests a special arrangement of knowledge construction taking place in the course of an imaginary journey. During the established *teacher-students discussion* around certain intriguing context the particular scientific knowledge is *mediated* by a teacher who detects and reacts to the difficulties revealed in the discussion. Moreover, instead of a unique context of presentation, TJ approach introduces a context of multiple perspectives, naturally incorporated in the script of a journey. Variation of perspectives presents the central cognitive tool of the TJ teaching. Students are guided to appreciate specific manifestations of the considered concept and their relationship with variation of environment in the course of the journey.

Here we will address a small part of the computerized program, the model of the Moon revolving the Earth and explain how TJ mediation facilitates a different learning reinforcing the common way of instruction.

Thinking Journey rationale

TJ intends to combine Feuerstein's method of Mediated Learning Experience (MLE, Feuerstein et al. 1980) and the constructivist approach to teaching physics (Driver & Oldham 1986, Driver et al. 1994). This mode tries to encourage conceptual learning of scientific contents through a special type of interaction between the learners and teacher. In this special route of learning, the teacher listens and guides the students suggesting how and what to observe in the considered representation of a certain natural phenomenon. The teacher acts as a collaborator and mediator in making scientific sense of the selected environment by students and as a facilitator of their need for information and tools for understanding.

TJ comprises a series of learning activities (*interactions*) organized in a scenario of imaginary, challenging, and often surprising, "thinking journey". The location of the learner in each interaction is explicitly determined. Thus, TJ appeals to the imagination, inviting

students to consider certain phenomenon from several perspectives. Visiting to an unusual environment is often followed by a "return back home". Students are invited to discuss their experience and compare between the different appearances of the phenomenon from the considered perspectives. Short interactions (student-teacher as well as student-student), during the TJ, stimulate both perceptual and conceptual changes. The change in students' knowledge is not realized by criticizing mistaken schemes of knowledge (e.g. Galili and Hazan 2000); at least, this is not the major focus of the activity. Rather, the change comes from a broadening of the initial knowledge, causing its growth, modification and maturation, stimulated by the variation of perspectives, eventually converging to the new understanding of the concept emerging as an invariant core of many appearances. This is the new way to reach conceptual change.

TJ applied in using astronomical model

The first TJ activities were suggested in the domain of astronomy, possessing a rich repertoire of images challenging students' imagination and attracting their curiosity. Therefore comparing common and TJ instruction is appropriate to make addressing operating the computerized model of the Moon revolving around the Earth. In the instruction using the model students observe one revolution of the Moon from the point of external and rempted observer. A flag is put on the certain place on the Moon, and it slowly rotates remaining towards the Earth during the whole circle (representing about 29 days). This is to demonstrate that the Moon preserves the same side towards the Earth. A special window shows the phases of the Moon as observed from the Earth during the circle. As mentioned already, students observe the animation and the teacher directs their attention to the special features of this reality:

- 1. The periodic motion of the Moon
- 2. The fact that the same side of the Moon faces the Earth
- 3. The phenomenon of Moon's phases, as observed from the Earth.

Several difficulties were detected in such instruction (Gazit et al. 2005). As a main cognitive difficulty the *egocentricity* of students was reported, that is, their inability to imagine any appearance of the situation but that from the point of view from the Earth. It was also stated that the ability to employ *multiple perspectives* to account for this natural phenomena is essential for the meaningful learning. However, no attention is usually given to develop this ability in students. The regular teaching solely presents the view of the imaginary outside observer, shown as problematic to many students (Gazit et al. 2005).

Teaching the same topic using TJ activity

Thinking journey can reinforce teaching the subject using the mentioned computerized model. Within such an approach students are invited to address the phenomenon changing the perspective of its observation. Each perspective allows the students to see the day-night cycle from a different point of view. The following perspectives are considered being supported with the pictures we brought next to the brief description of the correspondent interactions.

a. The first perspective: The Moon environment (Fig. 1)

Teacher suggests to the students:

"Put yourself on the Moon in the place where the astronaut stands (the place of the flag – in the model). Describe your immediate environment. Write down the questions that you have."

Students consider the environment of the Moon and not the Moon as a remote sphere.



Figure 1

b. The second perspective: The movement of the Moon (Fig. 2)

Teacher suggests to the students:

"You are standing on the Moon while it revolves around the Earth. Describe the way you view the Earth, the sky and ground of the Moon during the revolution of the Moon around the Earth. Describe the day-night cycle on the Earth and on the Moon."

Students imagine and compare the manifestations of the revolution of the Moon, as they are observed from the Moon and from the Earth, using both the computerized model and the picture.

c. The third perspective: Day-night cycle on the Moon (Fig. 3)

Teacher asks the students:

"You are standing together with the astronaut. Is it night or day at the place you are standing?Why do you think so?"

In the course of the TJ teacher asks:

"Time goes; will it be night or day in the place where you are standing in two hours?" (6 hours, 24 hours, 15 days, 27 days)."

Students consider the day-night cycle on the Moon, which is much longer than on the Earth (approximately a month).

d. The fourth perspective: Earth's environment (Fig. 4)

Teacher suggests to the students:

"Now imagine yourself returned home, to Israel, standing outside and watching the sky. Describe your experience now and address the way the Moon, the Sun, the stars, the sky appear to you?"

And he/she proceeds:

"Describe the day-night cycle now."

After the experience on the Moon, students consider the day-night cycle and the Moon's movement from the regular, on ground perspective ("returning home").

e. The fifth perspective: observation from a spaceship (Fig. 5)

The teacher suggests to the students:

"Now you are in a spaceship on the way to Mars. You are watching the Earth and the Moon from the window. Describe what you see. Relate your description to the daynight cycle of the Moon and to the day-night cycle of the Earth."

The considered at this stage perspective is similar to the one used originally in the mentioned computerized model. However, students arrive to it now after considering several different perspectives and they find themselves prepared to understand the subject as it is demonstrated



Figure 2



Figure 3



Figure 4



Figure 5

in the model. The day-night cycle is conceptualized in a broader context and thus are better understood.

Summary of the method

The described series of TJ interactions mediate understanding of the concept of day-night cycle learned by using the mentioned computerized model in a new way. Students experience a different learning which is based on the TJ activities. No longer this process presents general theoretical statements: facts, descriptions and explanations of the phenomenon in its unique ("representative") appearance, but the teaching includes a discussion on the subject in different environments arranged in an imaginary tour. Students are highly engaged and usually enjoy going through a variety of experiences. This type of teaching preserves students' interest in learning physics beyond the introduction, causing vivid discussions, debates and repeating observations of the same object.

TJ activities help students to acquire cognitive skills of changing perspective, conserving quantities and analyzing situations in terms of the common and different, performing analysis and synthesis of observations leading to growing of students' ability of logical inferences regarding the considered subject. Learning to consider what is conserved when situations change, to project the known relation to new situations they encounter, ability of space orientation, and breaking spontaneous egocentricity present enrichments of *cognitive skills* which all are required for a successful learning of physical concepts.

The important feature of the method is an explicit determination of the place of the learner in each considered situation and its frequent change. Students learn to see phenomena from various angles, connect and compare between them. TJ interactions encourage students to infer regarding certain *physical concept* from such comparisons and to personally build scientific concept, emerging as an *invariant* of its appearances in *different contexts* (Marton 2003).

Acquiring scientific concepts, significantly improves following students *observation of the details* of the considered image, picture or demonstration. The concepts learned this way get their basis in a broad perspective of appearances and variety of contexts. This feature of the method makes the acquired knowledge meaningful.

The mediation of the considered model of astrophysical nature through the TJ approach causes students' appreciation of the *complexity* of the model, awareness of its major components: the Earth and the Moon being in a relative motion, as well as the possible multitude of *different perspectives* in considering this system: from the Earth, from the Moon, from aside. Although such learning is challenging it is easily entered by a variety of students' populations.

Importantly, within the TJ approach students are provided with a *sufficient time* in order to make sense of the situation, construct and assimilate the meaning of the processes taking place. "Creative repetitions" in learning concepts with constant changes significantly improves students' success. Further empirical studies will provide better understanding of the processes taking places in the described method of teaching-learning and answer the variety of specific questions regarding the effectiveness of the method already observed.

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HYSTERSOFT – Software for the simulation of magnetization processes

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Abstract

Students often have difficulty understanding the phenomena underlying magnetization processes or the simulation of electric circuits in which the inductor is made of hysteretic ferromagnetic materials. HysterSoft is a complex, yet user-friendly software that allows users to numerically implement various phenomenological models of hysteresis, such as the Energetic, Jiles-Atherton, Hodgdon, and numerous Preisach-type models of hysteresis. This software can also be used to analyze and simulate electronic circuits such as nonlinear RL and RLC circuits consisting of hysteretic inductors. HysterSoft can be used for both research and educational activities, as well as for the development of other phenomenological models of hysteresis.

Simulation of magnetic hysteresis in phenomenological models

HysterSoft is a program for the simulation of hysteresis phenomena in magnetic materials. The goal of HysterSoft is to provide a user-friendly simulation framework in which various phenomenological models of hysteresis can be implemented by the users. The program comes with a few models already installed, but other models of hysteresis can also be easily added to the framework. Once a new model is added, for instance by writing a script file that describes the main equations of the model, HysterSoft is able to plot and analyze various magnetization processes or to describe the behavior of electronic circuits containing hysteretic inductors (for instance RL or RLC circuits in which the inductor is made by using a magnetic material which has hysteresis).

The HysterSoft framework was created to help students, engineers, material scientists, and researchers become familiar with and understand some of the current issues in the analysis, modeling, and simulation of hysteresis phenomena in magnetic materials. With the help of HysterSoft we can:

• Simulate various magnetization processes when the applied magnetic field is given. The user can define the applied magnetic field analytically or input different values at runtime.

• Simulate electronic circuits, such as RL or RLC circuits containing hysteretic inductors.

• Simulate rate/frequency-dependent magnetization processes. So far, two dynamic models of hysteresis have been implemented in HysterSoft: the effective-field and relaxation-time approximation models.

• Simulate aftereffect phenomena in magnetic materials. The aftereffect phenomena can be simulated by using the Monte-Carlo approach.

• Compute the First-Order Reversal Curves (FORCs) under different operating conditions (e.g. at different frequencies).

• Identify the parameters of the models by using experimental FORC data (in the case of the Preisach Model) or parameters on the major hysteresis loop (for other models).

• Simulate temperature and stress-dependent magnetization processes in magnetic materials (for now, implemented only for the Energetic model).

• Simulate inverse magnetic problems (i.e. computation of the magnetic field when the magnetization is given a-priory).

Model Implementation

HysterSoft was initially developed as a simulation environment for the Energetic Model of hysteresis. The program proved to be a useful tool for the simulation of magnetization processes in hysteretic materials and, later on, the Preisach, the Jiles-Atherton, and the Hodgdon models were added to the program. Currently, HysterSoft supports most models of hysteresis in which the output variable can be expressed as a function of the input variable in algebraic, differential, or integral form. A few models of hysteresis already come with the installation kit and other models will be added in the near future. The models currently included in the installation kit are:

- The Energetic Model
- The Hodgdon Model
- The Jiles-Atherton Model
- The Langevin Model
- The Classical Preisach Model
- The Generalized Preisach Model
- The Moving Preisach Model

In the case of the Preisach Models, the Preisach distribution function can be given analytically as a bivariate function, or numerically in a data file.

What Models Can Be Added to HysterSoft?

Most scalar hysteresis models in which the magnetization or the magnetic moment can be computed numerically when the magnetic field is given can be implemented in HysterSoft. The magnetization or the magnetic moment should be expressed in the form of an algebraic, differential, or integral equation of the magnetic field. For instance, in the case of the Energetic Model, the magnetization can be expressed as an algebraic equation of the magnetic field. In the case of the Jiles-Atherton and Hodgdon Models of hysteresis, the magnetization can be written as a differential equation of the magnetic field, while in the case of Preisachtype models, the magnetization can be expressed in integral form. These equations should be specified in a script file that should be copied in the installation directory of HysterSoft. Every time HysterSoft starts the script files are loaded by the simulation framework and placed in the "Scalar Models" menu.

New models can be easily added to HysterSoft by using script files. The script files should provide the analytical expression of the magnetic susceptibility as a function of current and past values of the magnetization and magnetic field. This feature of HysterSoft can be very useful for testing and developing new phenomenological model of hysteresis.

Software Installation and New Models Incorporation

HysterSoft can be installed on the following operating systems: Windows 2000, Windows 98, Windows ME, Windows NT, Windows XP. To install HysterSoft you need to download and install the HysterSoft setup file which can be found at www.eng.fsu.edu/~pandrei/HysterSoft [3]. It is strongly recommended that you install the latest version since, usually, that is the most stable one.

The latest version of HysterSoft (HysterSoft 1.5) was released in August 2006 and has undergone significant improvements from earlier versions. Specifically:

• The model identification techniques for the Energetic models were improved considerably.

• Electronic circuits comprising of inductors with hysteretic materials can be simulated by using dynamic models of hysteresis.

• Added capabilities to implement other models of hysteresis with the help of script files.

• Improved graphic interface.

• First-Order Reversal-Curve (FORC) analysis can be easily carried out in the framework of any model implemented in HysterSoft. By using the FORCs, HysterSoft can identify the FORC diagram (Preisach function).

• The Discrete Preisach Model (i.e. the generalized moving Preisach model in which the distribution function is given numerically) was implemented.

• HysterSoft functions can be called externally by using the HysterSoft library. For instance, HysterSoft can be called from Matlab, Fortran, C++, Java, or other languages.

The Assisted Test window (see figure 4) allows the user to resolve in a period of unlimited time a version of a test from a chapter, generated by the computer. The right answer version is immediately posted allowing the candidate to learn quickly. The evaluation can be made in any moment.

Future development

In the future we plan to add new features which will improve considerably the area of applicability of HysterSoft. These features include:

- Better graphical interfaces and data manipulation features.
- Debug possibilities when running script files.

• Increased circuit simulation flexibility. For now, HysterSoft can simulate only RL and RLC circuits with hysteretic inductors. In the next version of HysterSoft, the circuit will be designed by the user at runtime.

• The ability to work with vector models of hysteresis. So far, HysterSoft can work only with scalar models of hysteresis, but in the future it will be improved to also work with vector models of hysteresis. This feature will allow us to implement the 3-D Energetic Model, Vector Preisach-type models, and some micromagnetic models such as Landau-Lifshitz-type models.

• Implementation of more electronic devices containing magnetic materials (e.g. transformers and actuators).

• Direct communication with experimental devices. For instance, HysterSoft will communicate directly with Vibrating Sample Magnetometers (VSM) or other optical or low temperature magnetometers.

• Detailed documentation files.

Conclusions

HysterSoft is a powerful program that students and researchers can use to gain knowledge related to the analysis, modeling and simulation of magnetic materials. Users can analyze how magnetization curves are influenced by various parameters of the material, such as the demagnetizing factor, particles dimensions, coercivities and the interaction field in particulate magnetic materials, as well as by external conditions, such as the stress level and temperature. HysterSoft can also be used to study strongly nonlinear electronic circuits consisting of hysteretic inductors and nonlinear components. Through HysterSoft's user-friendly interface one can easily simulate complex magnetization processes in magnetic materials, which would otherwise require long and expensive experimental procedures.

Acknowledgements

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Student Involvement in Physics Modeling

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Abstract

We describe our experience in supervising undergraduate Physics students to produce computer models illustrating interesting physics concepts, including a game of leaky bucket, special relativity, eclipsing binary stars, close binary star systems, and electrorheological fluids. A feature of the projects is the requirement for students to make presentations to both university and high school students with the aid of the computer models.

1. Introduction

A major emphasis in university education is to promote the all-round development of students according to their own attributes. Important components in their development include skills of searching, discovering, integrating and organizing knowledge, collaborating with peers and communicating their ideas. Many of these objectives cannot be achieved through traditional modes of instruction such as lecturing. Instead, student participation in projects is much more effective.

In this paper, we will share our experience in introducing multimedia project courses to Physics students. While multimedia aids have become a popular means to enhance the teaching and learning quality, the major emphasis has been focused on the effects of the *final product*. On the other hand, our scheme emphasizes on the process of producing such multimedia aids, which also has very high educational values. Through the process of multimedia production, students learn to research on a topic, gather information from different sources, and synthesize them into presentable forms. They enhance their presentation skills through evaluation and feedback in rehearsal sessions. Besides, their collaborative and communication skills will be improved through assisting the juniors in a group environment. A feature of our scheme is the requirement for students to make presentations to both university and high school students. Presenting to high school students with non-technical background sharpens the need to improve the presentation skills. All these elements contribute to their all-round development. Descriptions of the early stages of the projects have been presented in [1].

2. Description

Our scheme works closely with the project courses for Physics students, initially offered to final year students and recently extended to include more junior ones. The students chose their own project topics and worked under the supervision of a faculty member. After the final presentation, students with outstanding progress and presentable topics were nominated to participate in the multimedia project. They were assigned the task of preparing a multimedia presentation at the popular level, and are required to study deeply the content of their project topic.

In the past few years, students in our department have completed the projects listed in Table 1, with presentations made to high schools. The scale of the presentations is described in Table 2. The program was extended to Biology and Mathematics recently. Multimedia aids or experimental demonstrations were used in the presentations to explain the complicated concepts and make the abstract ideas clearer and more fascinating. In this paper, we focus on several representative computer animations used in these presentations. The Chinese version of the presentation materials can be accessed on the web [2].

Table 1: Projects with presentations to high schools

Introduction to Mobile Phone Networks
Introduction to Special Relativity
A Voyage of X-ray Astronomy
Introduction to Pulsars
Life Out There?
Principles and Applications of Nano Science and Technology
The Science of Ultraviolet Radiation
The Physics of Microwave Oven
The Wonderful Butterfly
Adaptation in Nature (Biology)
Feasibility of Wind Power Generation in Hong Kong (Mathematics)

Table 2: The number of student presenters (both the students who conducted the projects and those who made presentations based on the original projects) and high school presentations organized for the projects.

Semester	Number of student presenters	Number of presentations
Spring 2003	11	10
Fall 2003	7	8
Spring 2004	11	25
Fall 2004	8	8
Spring 2005	15	17
Spring 2006	15	13

2.1. The Leaky Bucket

As shown in Fig. 1, the game consists of water drops stochastically entering the bucket and leaking out at the bottom. The player can use the tap to control the entrance of water drops. If the tap is set too loose, water will overflow. If a prescribed number of water drops overflow (set to be 20 in Fig. 1), the game is over. The player will try to maximize the collected number of water drops before the game stops. Of course, the player can play on indefinitely if the tap is tight enough, but then the water level in the bucket will not be high. The challenge to the player is to maintain the average water level as high as possible, while the overflow ratio is restricted to 1% or below. The player can then compare his/her performance with the automatic mode, in which the tap is controlled by an SDCA algorithm, obtained from recent research results [3].

The game is a good demonstration of stochastic processes. For a given tightness of the tap, the movement of the water level is a stochastic process described by a diffusion equation in

the presence of a boundary set by the capacity of the bucket. Knowing how the water level changes with time, we can control the water level. This method can be used in the control of wireless mobile networks, if we recognize the analogy in Table 3 [3].

The animation is a vital part of the high school presentation titled "Introduction to Mobile Phone Networks", and the game provided the audience with chances for active participation.



Figure 1: The leaky bucket animation game.

1% or below	the dropping probability to 1% or below

2.2. Special Relativity

The advantages of using computer animations to visualize the effects of time dilation in special relativity are illustrated in Fig. 2, which captures a moment of the animation with the moving car, and the moving photons of the clocks associated with the car and the stationary observer, Ben. A right triangle is drawn on the path of the car, such that the photon path of the moving clock coincides with the hypotenuse when the car passes by. Applying Einstein's postulate that the speed of light is constant, it becomes immediately apparent that the time on the car, as seen by Ben, is slower. The dilation of time was observed from the ticks of the two clock counters.

Other animations in the same production include the twin paradox, the dilated lifetimes of fast muons, and the train-and-tunnel paradox. The resolution of the twin paradox is easily visualized from animating the acceleration effects when the spaceship turns around for the return trip, and the train-and-tunnel paradox is readily resolved by animating the relativity of simultaneity as observed on the ground and on the train.

The animation is the main body of the high school presentation titled "Introduction to Special Relativity", generating the hottest discussions in the series.



Figure 2: Special relativity animation visualizing the effects of time dilation.

2.3. Binary Stars

The variation of brightness in eclipsing binary stars can be easily analyzed by undergraduate students with foundational knowledge of geometry and the Newtonian mechanics of star orbits. In Fig. 3, the animation shows the eclipsing effect in the binary system of Algol [4]. The configuration is displayed simultaneously together with the moving cursor on the light curve, allowing students to visualize the onset and offset of the primary and secondary minima. The stellar properties (mass, radius, and luminosity) as well as the orbital properties (size,
eccentricity, and inclination) are adjustable, allowing students to visualize the effects of these variables on the shape of the light curves.



Figure 3: The animation of the eclipsing effect in the binary star system of Algol.

Similarly, the Doppler effect of the light pulses emitted from a binary pulsar is easy to analyze by undergraduate students with foundational knowledge of Newtonian mechanics. Due to the large variations of the radial velocities of the pulsars along the highly eccentric orbits, and their dependence on the orbital orientation, students can observe a rich behavior of the family of velocity curves. Through the animation, students appreciated the relevance of the Doppler effect in the Nobel Prize-winning discovery of gravitational waves in binary pulsars [5].

Both animations were used in astronomy presentations to high school students, the public, and undergraduate astronomy courses at the general education level.

2.4. Close binary star systems

The physics of binary star systems is naturally extended to close binary star systems. New concepts such as equipotential surfaces are needed to describe the flow of matter between the partners, giving rise to many exciting developments such as X-ray astronomy and the discovery of black holes. Figure 5 shows an animation of the equipotential surfaces produced in an undergraduate project using foundational knowledge on gravitational potential energy and centrifugal energy. For adjustable masses of the two stars, the player can click on the vicinity of the stars to animate the equipotential surface passing through that point.

Figure 6 is an animation explaining the evolution of a close binary star system, ending up with a red giant and a compact object (white dwarf, neutron star, or black hole), which becomes an intense X-ray source when it devours matter from its partner. The animation provides a natural explanation to the so-called Algol paradox in astronomy, which refers to the apparently earlier aging of the less massive star in the Algol binary star system [4]. Both animations were used in the presentation "A Voyage of X-ray Astronomy" given to high schools.



Figure 4: Doppler effect of the binary pulsar.

2.5. Electrorheological Fluids

The recent discovery of the giant electrorheological effect in our department has been widely reported around the world [6], and created an overwhelming demand for presentations on the topic in the Hong Kong society. The animation represented in Fig. 7 played an important role in these presentations. An electrorheological fluid is a colloid consisting of nanometer particles suspended in a nonconducting liquid. It can reversibly transform from a liquid to a solid almost instantaneously by an external electric field, and hence has potential applications such as vibration damping and clutches. The animation portrays vividly the aligning of the nanoparticles in the electric field, rendering the physical principle transparent to the layman.

3. Impact

Besides the benefits to the all-round development of students involved in the producing the animations and making presentations in high schools, as described in the Introduction, there are further benefits to the training of future educators, and science education at both university and high school levels. We can cite the example of a student presenter whose performance in the high school presentations contributed to her successful admission to the Postgraduate Education Diploma.

Figure 5: The equipotential surfaces in a close binary star system.



Through the high school presentations, the newest and most updated scientific development can be presented to the public. This forms a bridge linking up the university and high schools. More high school students knew more about the everyday relevance of Physics, eliminating the misconception that it is a very difficult subject. According to a high school principal, the presentations broadened her students' scope of knowledge on frontier science beyond the original syllabus. In the presentations, the research projects were presented in an interactive way. High school students were encouraged to play an active role in learning because the presentations were not just lectures but also allow the students to participate. This aroused the students' curiosity in science.

4. Conclusion

We have described our program of physics modeling which involves students in the production process and presentations to the public. The program was successful in providing the students opportunities to study deeply a project topic of their own choice, to learn to produce multimedia aids and engage in instructional design. Their integration, collaborative and communication skills were improved. The requirement to make presentations to both university and secondary school students improve the confidence of the students. At the community level, the school presentations linked up the university and the high schools, providing the high school students and teachers with the most updated scientific knowledge, and arousing their curiosity in science.

Figure 6: The animation of the Algol paradox.



Figure 7: The animation showing the physics of the electrorheological fluid in an electric field.



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Teaching Physics Concepts

Explanatory Models on Buoyant Force: Results of an Inquiry with University Students

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Abstract

This paper will discuss the results of a research on explanatory models that university students possess about buoyant force. Research in Science Education has contributed to the understanding of students' learning through the modeling of students' reasoning. The idea of "model" as a personal construction has been treated from different theoretical perspectives. We understand that the explanatory model that a student constructs about a physical system could be a key to understand how he uses different ways of reasoning and alternative conceptions in different situations. The identification and characterization of explanatory models could help to understand why students seem to adopt some ideas close to those scientifically accepted in some contexts and, almost simultaneously, work with spontaneous ideas that are incompatible with the scientific ones. The working hypotheses focused on three aspects: students adhere to explanatory models that are related to buoyant force when dealing with problems where bodies are submerged in liquids (H1), there are groups of students that share the same explanatory model (H2), and there are students that selectively activate different explanatory models depending on the problem at hand (H3).As a result of this research, four coherent explanatory models were identified. Non empty sets of students that share each of these models were found. Some students were detected to have elicited different explanatory models in different contexts. These results provide favorable evidence to the stated hypotheses. More over, they are in accordance with previous investigations on the conceptions that students hold and allow to look at them from the explanatory models perspective.

Introduction

This paper presents the analysis of university students' explanatory models about buoyant force. The research stemmed from the need to find out why students seem to adopt ideas that are closer to those scientifically accepted within some contexts while simultaneously using spontaneous conceptions within other contexts.

For many years, research was focused on identifying students' ideas about the world. Students' conceptual difficulties and misunderstandings in learning were described, for example in Hierrezuelo & Montero (1998), and Driver, Squires, Rushworth & Wood-Robinson (1994) among others. Several of these contributions have dealt with the analysis of the general characteristics of the students' naive conceptions. Ausubel stated that the most important factor influencing learning is what the student already knows (Ausubel, Novak, & Hanesian, 1983).

In addition to the identification of these naïve ideas, research also focused on studying the "reasoning patterns" (Viennot, 1996). Some of these patterns cannot be associated with specific conceptual fields. For example, she describes the "functional reduction" that students perform when they put aside some variables involved in a concrete problem. Moreover, Viennot (1998) puts forward the notion that students' responses vary according to the context of the problem being analyzed.

Currently, there is a growing concern about answering new questions: Are students' conceptions organized as some kind of structures? If they are, can these structures be characterized in some way? These questions are currently investigated through different theoretical frameworks among which are those that refer to students' models and modeling.

From the point of view of Physics' epistemology, authors such as Bunge (1985), Estany (1993), Cudmani, Salinas & Jaén (2000) agree in stating that the scientific modeling activity is characterized by the processes of cutting and simplification of the system under study. These processes take place through the disregard of certain intervening factors that are considered

irrelevant or negligible in the light of the assumed hypotheses. In other words, intentional simplification and cutting are performed so that the physical system under study can be described through a limited number of variables, that is to say, through a model.

Within the field of Science Education Research, students' models are understood as personal constructions that are described from different theoretical perspectives. Some representatives of these perspectives are, among others: Johnson-Laird (1983) and Holland, Holyoak, Nisbett & Thagard's (1986).

In this paper, we assume that the students construct explanatory models that allow them to explain and predict how a physical system works. These models have an underlying implicit or explicit structure of concepts.

The students' explanatory models often differ from the scientific models. The first ones may include non scientific intuitive ideas as well as some scientific ones. Physicists can use different scientific models to explain a phenomenon depending on their theoretical commitment. This underlying theory is what determines which the relevant variables are and which ones are negligible or can be discarded. Students also select some variables that allow them to describe the physical system. In performing this selection they cut and simplify the problem under study, but usually they don't refer to an explicit model or theory, many times the choice of relevant variables in non intentional and the variables they select are often linked to perceptual characteristics of the system (for example, the body's volume, the amount of liquid in the container).

The resulting explanatory models are dynamic since students seem to construct them on the basis of their interaction with the problem at hand. A change in the context of the physical situation may result in a change of the student's explanatory model. In other words, a student may have a set of coexisting explanatory models for equivalent physical situations and he may activates one or another according to the context of the problem being analyzed. The activation of a certain model might be related to those variables that the student considers relevant for the description of the problem.

The explanatory model about a particular physical system might provide a clue to understanding the way in which students use different types of reasoning and alternative conceptions in different situations. Thus, the hypotheses that guided the present research were:

H1: Faced with problem-solving situations that involve submerged bodies within liquids, students use explanatory models about buoyant force.

H2: There are groups of students who share the same explanatory model.

H3: Students may have different coexisting explanatory models and use one or another depending on the context of the problem at hand.

Methods

The research methodology is described in detail in (Alurralde & Salinas, 2006). It consisted of two stages: the spiraled exploratory inquiry and the hypotheses testing that were carried out through questionnaires and interviews.

First, the whole set of answers given by the total group of students were categorized according to those variables that were considered relevant for the explanation of a physical situation. For example, the answer "The buoyant force depends on the body's volume" was categorized as B3. This category included all those answers that explicitly named the body's volume as a relevant variable for explaining the buoyant force. The answers of each student were then described as a set of categorized statements. Most of the times, the answers given by a single student were composed by statements that belonged to different categories.

Then, category groupings were defined through the detection of certain category patterns within the explanations given for physical situations. For example, explanations of the buoyant force that were based on the body characteristics and did not consider the liquid as playing any role were clustered in a category group.

Results

Table 1 shows the identified answer categories. Category NA includes answers that were ambiguous, those that were based only on equations, and those of no reply at all.

A1 The buoyant force depends on the volume of liquid displaced.

B1 The buoyant force depends on the weight/mass of the body.

B2 The buoyant force depends on the density of the body.

B3 The buoyant force depends on the volume of the body.

C1 The buoyant force increases when depth increases.

C2 The buoyant force depends on pressure.

C3 The buoyant force depends on the density of the liquid.

C4 Student does not discriminate buoyant force/pressure.

D The buoyant force depends on the horizontal surface of body-liquid contact.

E1 In the presence of other forces student does not know how to explain the buoyant force.

E2 The buoyant force does not act or is less when the body is in equilibrium.

E3 The buoyant force depends on the connections.

G1 The buoyant force is greater if the body is higher (degrees of floatability).

NA Non-usable answers.

The category groupings that were detected were interpreted as indicating the students' commitment to different models:

Scientific Model: comprised by answers consistent with the scientifically accepted model. Those students who seem to be committed to the Scientific Model exclusively use answer categories A1 and C3.

Model 1: The variables considered relevant for buoyant force are those linked exclusively to the submerged body (mass, weight, density, volume). Those students who seem to adhere to Model 1 use answer categories B, but do not use answer categories C (except for C3 which might be used on certain occasions).

Model 2: The variables considered relevant for buoyant force are linked only to the fluid (pressure, depth). The students who seem to adhere to Model 2 use answer categories C, but do not use answer categories B.

Model 3: The higher the body is in the liquid (at lower depth), the stronger the buoyant force is. This model seems to define a "flotation degree" for bodies, associating a stronger buoyant force to bodies that are closer to the surface.

Those students, who present category groupings which are related to the models defined above, were codified as MC, M1, M2 and M3 respectively. Those students who seemed not to be committed to any of the defined models were coded as NM (No Model).

A further analysis of the NM students' answers was performed. This analysis allowed the detection of some students who, under physically equivalent situations, gave different explanations depending on the context of the problem at hand. This behavior could be taken as signaling the presence of question-answer pairs (QA pairs), in accordance with Viennot's proposal (1998) as shown in Table 2.

Туре	Alternative explanations						
QA	For bodies partially submerged, they	For bodies completely submerged, they					
	adhere to Model 1	adhere to Model 2					
QA1	In the absence of connections, they	In the presence of connections, the buoyant					
	adhere to Model 2.	force depends on the connections.					
QA2	In the absence of connections, they	In the presence of connections, the buoyant					
	adhere to the model accepted	force depends on the connections.					
	scientifically						

Table 2. Students' Q-A Type responses

Table 3 shows the number of students who seem to adhere to each of the proposed models and the number of students who give Q-A type answers. This data were gathered during the hypothesis testing stage. The NI (No Information) Code refers to those students who present 50% or more NA answers.

Group		Mode	lel / NM Model / Q-A Pairs		Q-A Pairs	Scientific Model/ Non- scientific Model		
Code	Nº	N°	%	N°	%	N°	%	
MC	25					25	29%	
M1	5			12	49%	37	44%	
M2	5			42				
M3	7	62	73%					
PR	0			20	24%			
PR1	5							
PR2	15							
NM	23	23	27%					
Useful totals	85	85	100%	59	73%	62	73%	
NI	12							
Total	97							

Table 3. Percentage of students who respond according to models and QA type answers

Conclusion

Our findings show that it is possible to interpret students' answers as elicitations of different explanatory models. The obtained results are compatible with the first hypothesis (H1), which holds that the students' conceptions are not always a set of isolated notions, but rather notions that can be organized as conceptual structures (explanatory models).

At the different stages of the research, non empty sets of students who seem to adhere to each of those models were found, yielding favorable evidence to the second hypothesis (H2).

The detection of students that give Q-A type answers shows evidence that supports the third assumed hypothesis (H3).

The results obtained in this research not only do agree with the results of former studies on important aspects, but they also show an alternative approach to study students' learning difficulties.

These results suggest that future research is needed in the design and testing of teaching strategies from the theoretical perspective of students' learning adopted here.

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A Pedagogical Approach to Modelling Electric Conduction in Solids.

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Abstract

We present a pedagogic approach aimed at modelling electric conduction in metals, built by using the modelling environment Net Logo, and describe some related activities. The reported examples have been experimented during the laboratory courses of the Italian Pre-Service School for Physics Teacher Education (S.S.I.S.).

Introduction

Computer modelling and simulation tools can help physics teachers to focus on relationships between macroscopic and microscopic properties of matter, enabling students to model systems directly at the level of their individual constituent elements and their interactions, in order to understand emergent macroscopic properties.

The benefits of multi-agent simulations for understanding how a variety of complex behaviours derive from simple interactions of local agents are today well known [1]. A core feature of multi-agent simulation environments is that students can apply a small number of rules to capture fundamental causality structures underlying behaviours in a range of apparently disparate phenomena.

Building a model by thinking in terms of individual agents appears to be intuitive, particularly for the mathematically uninitiated [2, 3]: the related pedagogic activities may be centred on an approach to learning physics that follows the same steps than learning a new language [4].

Here we present some pedagogic procedures aimed at relating measurements of electric properties of conductors with "virtual experiments" built by using NetLogo [5]. Models of both classic and quantum electric conduction in metals, such as the Drude-Lorentz and Sommerfeld ones, have been implemented. The different model predictions about the resistivity vs. temperature dependence and some related parameters have been related to experimental results.

The reported activities have been experimented during the laboratory courses of the Italian Graduate School for Physics Teacher Education (S.S.I.S.).

Experimental results

Resistivity vs. temperature measurements have been performed in the context of an education project aimed at studying electric conduction properties of solid conductors, semiconductors and superconductors [6].

Measurements have been performed by using an electronic board allowing to take data of the electric current circulating in a sample when it is subject to a given voltage, as a function of the sample temperature. The board is designed to study the resistance of high T_c superconductor samples but we have modified it to take also measurements with conductors and semiconductors. Here we report only the data taken in conductors.

The resistance data at low temperature values are taken by suspending the metallic sample in a thermally insulated container and letting it cool under the action of liquid nitrogen vapours placed in the container. Current and voltage, as well as temperature data have been collected by using digital multimeters connected to the electronic board, as shown in figure 1.

Fig. 1. The experimental apparatus.



Figure 2 shows data taken by using a thin copper wire, of length L = 0.5 m and cross sectional diameter $d = 2 \times 10^{-4}$ m.



Fig. 2. Resistivity vs. temperature in a copper wire.

A linear dependence of resistivity from temperature is evident, as expected for a conductor in the range of analysed temperatures.

From the well known resistivity vs. temperature formula

$$\rho = \rho_0 \Big[1 + \alpha \big(T - T_0 \big) \Big]$$

and from the linear fit parameters reported in figure 2, it is easy to obtain an estimate of the temperature coefficient α in copper. ρ_0 is the resistivity at $T_0 = 273$ K.

$$\alpha = (4.07 \pm 0.04) \times 10^{-3} \frac{1}{K}$$

This value is in accordance with the expected value for α in copper [7].

These results are in good agreement with other measurements [8] aimed at help students to better understand the electrical behaviour of conductors and semiconductors.

Modelling

Microscopic models describing and explaining the experimental results have been implemented by using classical and semi-classical models implemented in NetLogo.

The main pedagogical purposes of such simulations can be summarized as follows:

- to emphasize the fundamental concepts related to electron motion and electroncrystal lattice interactions as key concepts to understand the electron transport phenomena and the effects of temperature variation;
- to supply a deep understanding of microscopic conduction mechanisms and their modifications due to the temperature, emerging from different and more refined microscopic models of metals.

The implemented models share some characteristics with well known historical models and will be described in the following.

The first and simplest model, fitting some of the conduction properties of metals, is the 'Drude-Lorentz model'. It considers the electrical conduction as due to a "gas of free electrons" moving through a lattice of fixed ions, against which they collide. If an electric field is applied, electrons, of charge *e* and mass m_e , are subject to an acceleration eE/m_e . The whole effect of collisions is viewed as a viscous force, counterbalancing the electrical force and maintaining constant the velocity of electrons.

If n_e represents the number of free electrons in a unitary volume and v_d is the drift velocity of the electrons, i.e. the mean velocity of the electrons in the field direction, the metal resistivity can be written as:

$$\rho = \frac{E}{n_e e v_d} \tag{1}$$

The mean time τ between collisions is expressed in term of the electrons' mean thermal velocity v_m and of the total cross-sectional area A for the electron-ion scattering.

$$\tau = \frac{1}{n_e v_m A} \tag{2}$$

The drift velocity and the metal resistivity can be related to τ by the formulas:

$$v_d = \frac{eE}{m_e}\tau, \qquad \rho = \frac{m_e}{n_e e^2 \tau} \tag{3}$$

The crucial point in this microscopic representation ("relaxation time approximation") lies in the interpretation of v_m and A. Our simulations use three different interpretations or 'pictures': the 'Drude-Lorentz' one, the 'Full classic' picture and the 'Semi classic Sommerfeld' picture, described in the next section.

Model implementations

The models have been implemented by using NetLogo 3.0.2 and NetLogo 3D preview 1 [5]. We consider a small volume of copper containing the same numbers (about 100) of free electrons and ions arranged in a regular three-dimensional crystal lattice. Electron and ions are modelled as small elastic spheres of given mass and dimension. Electron-electron and ion-electron Coulomb interactions are not considered. Consequently, the trajectory of an electron is a straight line/an arc of parabola, in the absence/presence of electric field E.

Although the simulation runs in a three dimensional space, the system can be visualised both in three dimensions (figure 5) and in a two-dimensional projection (figure 6).

Fig. 5. NetLogo 3-D visualisation of electrons moving in the ion lattice.



Fig. 6. A two-dimensional projection of the 3-D space and the simulation result: the graph of electron drift velocity as a function of time.



The user can choose one of the three models previous described, set the temperature and the electric field strength and perform two different types of 'virtual experiments': a) by varying the field strength at a constant temperature; b) by varying the temperature at a constant field strength. The program output is the electron drift velocity as a function of time. When the drift velocity reaches its steady value it can be acquired and the resistivity value is calculated (1). With several values of resistivity corresponding to different temperature a graph of ρ as a function of T is built.

The detailed implementation of the three models presents some differences, both statistical and dynamical, reflecting the different characteristics of these models.

Drude-Lorentz model

Here the electrons have a velocity distribution in accord to Maxwell-Boltzmann statistics. Then, to a given temperature T, v_m corresponds to the mean square root velocity v_{rms}

$$v_m = v_{rms} = \sqrt{\frac{3kT}{m_e}}$$

The lattice ions are considered at rest with a radius equal to ion radius (for copper, $r_0 = 0.361$ Å).

The electron-ion collisions are treated as perfectly elastic and no dissipation mechanisms are considered. For not too high electric field strengths (below 100 V/m), the system reaches a steady state condition in which the dynamical quantities, such as drift velocity and mean relaxation time, are constant (figure 6). By changing the system temperature (i.e. the value of v_{rms}), a plot of resistivity as a function of *T* can be obtained, as shown in figure 7.





'Full classical' model

In this model we take into account the ion oscillations by assuming that they depend on the temperature. From theoretical considerations it is possible to assume that the effective maximum oscillation amplitude is proportional to $T^{1/2}$.

The effective ionic radius r is assumed to be equal to the maximum oscillation amplitude. Electron-ion collision is assumed to be elastic, with exchanges of energy and momentum. We also consider a dissipation mechanism in the model, by keeping ions in equilibrium with a thermal bath at constant temperature.

Figure 8 shows the resistivity vs. temperature data obtained in the temperature range 100K - 700K. As expected, results of this classical model are in discordance with the experimental results (see figure 2).





Semi-classical Sommerfeld model

The implementation of this model differs from the previous ones since here the quantum nature of electrons is taken into account by considering the Fermi-Dirac statistic. Then, in the temperature range of interest, the distribution of electrons velocity is almost independent from the temperature. As in the previous models, the electron-ion interactions are considered perfectly elastic.

Fig. 9. Resistivity vs. temperature graph obtained by implementing the semi-classic Sommerfeld model within the simulation.



The result obtained with the semi classical Sommerfeld model (figure 9) are in good agreement with the experimental data, reported in figure 2 : the linear dependence of ρ from temperature is found and physical parameters, like the temperature coefficient and the resistivity values at T = 273K, are close to the ones obtained from the real experimental data.

Discussion and conclusion

Our models are based on a few fundamental rules of atomic interactions that exhibit emergent behaviours reproducing important aspects of the properties of materials, as electric conductivity.

There are several features of our pedagogical approach that may contribute to student learning. In our simulations, the same underlying computational model appears in different contexts and gradual modifications of the model are outlined. This provides several advantages:

- students gain familiarity with different representations and ways in which electrons behave and interact with nuclei;
- the model parameters can be set by the student, in the same way in which they interact and control the experimental parameters;
- the macroscopic properties of the model emerge from the details of the atomic-scale interactions in just the way that the corresponding properties emerge in real atoms.

A preliminary analysis of prospective teachers worksheets allows us to infer that laboratory activities, scaffolded by modelling, can improve students' learning about actions and interactions of individual objects resulting in emergent system properties.

Prospective teachers showed a better understanding of the difference between simply describing a situation in terms of equations and interpreting it on the basis of mechanisms of functioning. After the lab part of the workshop, prospective teachers showed a renewed attitude to search for interpretative models, even involving microscopic interactions, explaining why a phenomenon develops in a given way or some specific experimental results are obtained.

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Video's Resources to support Conceptual Physics Learning

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Introduction

The understanding of conceptual physics in the classroom is a difficult cognitive process for inexperienced students when they can not connect the real world of physics phenomena with science models. Commonly, physics students have their own perceptions of the world that surround them, however when they are asking to explain their daily experience with scientific arguments learning in physics classes, they use their own intuitive models. For example, mechanical phenomena are tightly linked with the world where the students live, but as the mechanical concepts understanding are so difficult to them they prefer to use simple ideas to explain the phenomena instead of applying correctly Newton's Laws.

How can we help our students to have a better understanding of conceptual physics?

We are experimenting with video as a resource to help the comprehension of our students in class. The purpose to include video resources in a class is to create a learning cycle where the students can be involved in a discussion of a simple experience which they need to explain through of recording and analyzing a video. They are encouraged to build a complete physics model about the phenomenon they are studying by their own. The next step to the cycle is to begin with a more complex situation which is not really well known by students, but they can analysis it under a conceptual point of view and try to predict what will happen if they prepare a real experiment. Then they will have the opportunity to confront their ideas directly by making an experimental activity, analyzing the corresponding video recording and proving their own predictions.

In brief words, we can conclude, that: what you see, you can think, but the most important think is what you think you can see.

Conceptual Learning Cycle.

The Conceptual Learning Cycle (CLC) is a way of learning concepts that it can be used in physics learning as a strategy where the students are confronted with a conceptual physics situation which they need to understand step by step. The students follow the next trajectory of mental and practical activities:

- 1. CONCEPTS. Students are confronted with a theme that it involves an important body of conceptual physics.
- 2. DISCUSSION of a physics phenomenon. A physics phenomenon is used to focus the concepts that are included in it. Groups of students discuss the phenomenon under study.
- 3. Intuitive EXPLANATIONS. Students try to give an explanation of the phenomenon with their own words. That explanation is taking as a first model, possible naïve model but that it discover the thought of students.

- 4. EXPERIMENTAL ACTIVITY. The students proceed to carry out an experiment that illustrates the studied phenomenon. They make very careful observations and confront their ideas with the things observed.
- 5. VIDEO RECORDING. If the students find differences between their ideas and the observed phenomenon they proceed to record a video clip (small video) of the phenomenon.
- 6. VIDEO ANALYSIS. Students study the video clip frame by frame using different techniques.
- 7. More FORMAL MODEL. Students give new explanations of the phenomenon. They express them by applying conceptual physics as it is possible, for example laws and principles.
- 8. New COMPLEX PHENOMENON. Students study a new phenomenon more difficult than the previous studied phenomenon but inside of the same conceptual body that contains the first phenomenon.
- 9. MODEL APPLICATION. Students must apply the formal model that they found previously to the new situation.
- 10. THINKING EXPERIMENT. Students are encouraged to make predictions and to think an experiment that can be used as the proof of their predictions. It is possible to think an imaginary experiment that it is difficult to make in the laboratory.
- 11. CREATIVE ACTIVITY. Student plan and make an experiment which simulate the general conditions of the thinking experiment.
- 12. VIDEO's TEST. Students record a video to prove their prediction. They need to establish the conditions under it will be made the experiment.
- 13. CONCEPTUAL RETURN. Students come back to the beginning, with the original conceptual ideas but with a more enrichment thinking. They summarize the founded ideas by themselves in a scientific language and end the cycle.



EXAMPLE.

- 1. Concepts: FREE FALL
- 2. Discussion of a physics phenomenon. Galileo's experiment of Pisa Tower.
- 3. Intuitive explanations. Aristotelian explanation.
- 4. Experimental activity. Dropping two bodies of different mass.
- 5. Video recording. Recording the falling of the two objects from the rest at the same time without any conditions of the height to those that are released.
- 6. Video analysis. The edition frame by frame of the video is analyzed by students.
- 7. More formal model. Students approach to the Galileo's explanation.
- 8. New complex phenomenon. Inside an elevator in free fall is a person that drops two bodies of different masses at the same time from the same height.
- 9. Model application. All the objects are falling at the same acceleration, and when the person leaves free the balls they continue falling like the person and the elevator. But in relation of the person they are in rest respecting him, that is, the acceleration of the balls respecting the person and the elevator is zero (The consequences of this fact direct us to the Equivalence Principle, but this discussion is taking apart for the moment).
- 10. Thinking experiment. If we are in a g-accelerated spaceship we don't know if we are freely falling to the Earth or we are in the free space with g-acceleration.
- 11. Creative activity. A wood box is assembled with a video recording camera (Web camera) inside and two balls of different masses attached to the roof of the box by means of two external electromagnets. All the system is hanging meanwhile the electromagnets are turn on, but when they are turn out all the things of the system fall to the ground.
- 12. Video's test. The video record inside the box shows that the balls are in rest respecting to the camera (only during the fall).
- 13. Conceptual return. All objects fall to the Earth with the same acceleration, but if it is true all the objects are falling together to the ground when they are dropped from the same height at the same time from the rest. For this reason the two

objects fall together to the floor, without caring if they are inside or outside of a box.

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Teaching and Learning Physics with Interactive Video

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Quantifying the magnetic field pattern: Ampere's law. A teaching sequence based on physics education research

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Abstract

This paper presents a pedagogical approach to address students' difficulties, identified in a previous study (*GIREP 04 Proceedings*, 170-173), in the learning of Ampere's law. The teaching approach developed in this work proceeds from the fundamental assumption that learning and teaching sciences is developed as a process of the solving of open tasks or problems which students could find interesting. The approach was developed within a rigid timetable and the programme of Physics for Engineering was the same for all the students participants in this study. The study groups were organised into small groups of 4 students which carried out the proposed activities and then discussed their conclusions with the whole class, under the teacher's management and guidance. The students work with the same methodology throughout the whole course, so the methodology used in the "Magnetic field" chapter is not new to them. The teaching sequence was mainly evaluated by two questionnaires which aim to test the students understanding of Ampere's law by a systematic analysis of its application in different situations. The results show that students in the experimental groups have a better understanding on Amperes' law than students who receive traditional teaching.

Introduction

This paper presents a pedagogical approach to address students' difficulties, identified in a previous study, in the learning of Ampere's law for magnetostatic [1]. We will only consider situations of stationary currents, so that the magnetic fields are stationary. We must remember that there is no a thing as a static magnetic situation, because there must be currents in order to get a magnetic field (and currents can come only from moving charges). "Magnetostatic" is, therefore, an approximation. However, in the syllabus of Introductory Physics Courses it is usual to teach a chapter considering only situations of stationary magnetic fields. In this research we take into account this context to teach Ampere's law for magnetostatics, which is an incomplete version of the Ampere-Maxwell law [2]

Despite its very different form, Ampere's law is essentially equivalent to the Biot-Savart law. However, in this interpretation we take into account the concept of field, which includes retardation and this is the reason why Ampere's law is relativistically correct, whereas the Biot-Savart law is not. Ampere's law holds in many stationary magnetic situations and the understanding of this law is an essential condition of reaching a scientific view of Maxwell's equations.

Previous investigations into students' difficulties indicate that students may have problems applying the concepts of electromagnetism [3, 4]. The case of Ampere's law included situations defined by mathematical operators and several variables which raises well know difficulties [5]. These difficulties have been analyzed in previous research [1] which shows that the majority of students use the following patterns of reasoning: to confuse the field operators (path integral of field) that provide information about the field and the field itself, to associate the path integral of magnetic field zero to value zero of field, to consider that the magnetic field is constant in any situation, to ignore the sources of the field (electric currents) which are outside the path.

The fact that the difficulties detected seemed resistant to usual teaching, as well as our analysis of textbooks [6, 7], induced us to design a teaching sequence to help students overcome these difficulties. So, the research question of our study is the following: How can we design a programme for teaching Ampere's law that improves students understanding of ampere's law? What learning is achieved by the students after implementing the programme in class?

Teaching approach

The teaching approach developed in this paper proceeds from the fundamental assumption that learning and teaching sciences is developed as a process of the solving open tasks or problems which students could find interesting. These are developed in a similar context, as far as possible at each level, to that of scientific research. Our proposal is specified by a collective work of *oriented research* [8]. We use the metaphor of the *"junior researcher"* whose role would consist of replicating research which is already known by "its supervisor" (the teacher). It is necessary to emphasis that this is not a matter of the students constructing scientific knowledge by themselves which took the most important scientists so much time and work, but to put them in a situation where they can familiarise themselves with scientific work and its results, covering known problems. In this approach, students are expected to prepare for class by reading and trying to do initial activities. This students initial implication allows teaching focus on the most important and difficult elements. The initial activities and reading act as an incentive to prepare the class for cooperative activities and discussion. In this part of the teaching process, students receive credit based on effort rather than correctness of their answers, which allows focusing on teaching the most challenges elements.

The teaching strategies based on Learning as Oriented Research (LOR) display three interrelated dimensions which can help students learn more and better (see figure 1).



Figure 1. The three dimensions of teaching proposal based on learning as oriented research.

Another element of our instructional approach is that we use formative assessment. The main reason for this is the extensive science education literature showing that formative assessment can improve teaching and learning when it is done consciously and systematically.

The approach was developed within a rigid timetable and basic programme context established for the subject of Introductory Physics for Engineering. The groups of this investigation consist of students enrolled in the introductory physics course of engineering degree at University of the Basque Country. The students on the course had to pass a test to enter to the University and their average age was 19 years old. The participants in this study were 114 students in 3 different groups (30 students Group 1, 32 students Group 2 and 52 students Group 3). The authors of this paper served as the instructors. The students work with the same methodology throughout the whole course, so the methodology used in the "Magnetic field" chapter is not new to them. This chapter was developed over a period of three weeks (12 hours) and implemented during four courses (2001-2005).

Two control groups were included made up of 65 students with the same characteristics as the experimental students but they received traditional instruction. These two groups are referred to as Group C. The entry level of the students in all the groups can be considered as similar and with a standard knowledge level in accordance with a previous study within this same research.

Table 1. Learning Demand Analysis: The Ampere's Law

Aspect of Science to be addressed	Students' difficulties
Ontological aspect	
Field lines are imaginary representations of the magnetic field generated by all currents in the universe	Field lines are real lines which can interact among them
Conceptual aspect	
Ampere's law established the relation between the path integral of magnetic field (circulation of field) and the sum of the enclosed currents. All currents in the universe contribute by superposition to the magnetic field, yet Ampere's law refers only to those currents inside the chosen path because the outside currents contribute zero to the path integral	 Confusion between the sources of magnetic field and the currents inside the chosen amperian path. So that, confusion circulation of field and the field itself.
Epistemological aspect	
Ampere's law is generally applicable to all situations, however only is useful to calculate the magnetic field in special circumstances which have certain simple symmetries.	The magnetic field is constant in any situation in which Ampere's law is applied, so the law is useful to find the field in any circumstance.

Based on the learning demands of table 1, an instructional sequence was developed. In the chapter "Magnetic field", it was presented to students, different task related to Ampere's law essentially based on the analysis of situations involving: a) the pattner of magnetic field and symmetry conditions; b) Choose a mathematical closed path as a boundary and stretch an imaginary soap film over the boundary; c) interpreting the circulation of field walking around the boundary; d) Add up the positive and negative currents that pierce the soap film and finally, applied Ampere's law.

Implementation and evaluation

The successive teaching sequences were mainly evaluated by the two questionnaires which we used to detect students' difficulties. The questionnaire 1 was designed to test students reasoning about the sources of magnetic field and Ampere's law application (first conceptual aspect of table 3) and the second questionnaire was designed to test students' understanding about the difference between magnetic field and the circulation field (second conceptual aspect of table 3). In all questions, for solving them correctly, students have to use the ontological and epistemological aspects of the table 3.

The evaluation of the teaching sequence is done by comparing our teaching approach with students who had other 'standard' teaching approach (the control group). In this paper we are going to present the result of the 2004-05 scholar year (see table 2). The statistic t-test was calculated for the control group and the average of the experimental groups obtaining significant differences with a level of confidence below 1%.

	Percentage of correct answers (%)					
Number of item and concept	Group 1	Group 2	Group 3	Group M [*]	Group	t
	N =30	N = 32	N = 52	N =114	С	p<<0,0
					N = 65	1
Q1. Solenoid	27.5	36	26	29.8	9	4.79
Q2. Three sources	76	59.5	61.5	65.6	8	6.8
Q3. Two sources	45	56	42	47,6	9	3.24
Q4. Circulation zero	83	72	61	72	18	6.45
Q5. B different	86	75	80.5	80.5	13	8.67
Q6. No symmetry	30	38	28	32	9	5.3

Table 2. Results obtained in the questionnaire by experimental and control groups

* Average of the experimental groups

While the averages provide a way of comparing differences between the groups, they do not directly reveal information about the students contextual coherence. Figure 2 presents the percentage of students who demonstrated contextual coherence from the 5 or 6 questions, according to the criteria given in table 1.



Figure 2. Percentage of students who respond correctly 5 or 6 question

Conclusion

The evaluation of the teaching approach, although limited to three groups of students, shows that the students show noticeable improvements in raising and resolving problems related to Ampere's law. Correct results were also obtained in learning on magnetic field sources and the explicative model of the Ampere's law, which are statistically significant in all cases from the control groups.

Reproducibility is an important prerequisite for science education progress. In this sense, we want to emphasise two aspects: The first deals with the context in which the programme of activities was developed. We were restricted by the programme laid down in the study plan. So, it was necessary, to produce a very detailed teaching plan of the time available and, showing that traditional conceptual contents were not lost as result of working with different teaching methodology. On the contraire, the designed and implemented learning sequence showed to give rise to enhanced learning outcomes when compared with those from a parallel class of students.

The second aspect deals with the role played by the teacher in developing the teaching sequence. The teacher has a strong influence on what and how the topic is taught, however as researchers we should make the effort to prepare a detailed guide for the teacher, as well as organise discussion seminars on the proposal where teachers would have the opportunity to discuss it and share ideas. Moreover, the teacher's role becomes highly important in our approach in terms of his own professional development, since he becomes an action researcher who will make his own critical reflection after the educational interactions and will therefore improve his educational action.

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Year 12 Students' Mental Models of the Nature of Light

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Abstract

This paper reports on the third year of a three-year longitudinal investigation into six Year 10 secondary students' understanding of optics at a secondary school level. During the first two years of the study the students' understanding of geometrical optics was explored with the adoption of constructivist teaching and learning strategies. The students' understanding of geometrical optics following the Year 11 teaching stage then formed the basis of exploration of their mental models of the nature of light. This exploration occurred before, during, and following a Year 12 teaching stage where the students studied physical optics and quantum ideas. Before the Year 12 teaching stage the students had constructed mental models of light that related to their understanding of a ray. Over the Year 12 teaching stage the students' mental models changed to conceptualizations of a photon. There was evidence in the students' mental models of a hybridization of the particle and wave scientific models. That is, they conceptualized the photon as having both wave and particle characteristics. The variation in the students' hybrid models also suggested a variation in the way they conceived of the nature of scientific models.

Introduction

The models of science are representations of objects, events, ideas, systems or processes (Gilbert, 1995). Scientific models are one of the main products of science (Gilbert, 1994; Halloum, 1996) and play a crucial role in reducing the complexity of phenomena by allowing a more visual reproduction of abstract theories so that predictions of behaviour can be made and tested (Gilbert, 1995). Scientific models help individuals conceptualise reality and serve as a bridge between the mind and the material world. For example, in conceptualising the behaviour of light secondary school students study two scientific models, referred to as the wave and particle models.

In interacting with the environment individuals construct mental models that are interpreted and understood in relation to existing mental models. The constructed mental models provide the individual with predictive and explanatory powers for understanding the interaction (Driver, 1995; Norman, 1983). Mental models are mental representations which individuals generate during cognitive functioning and have structures that correspond to, but do not directly represent, a structure in reality (Johnson-Laird, 1983; Vosniadou, 1994). Therefore, before studying the scientific models of light secondary school students will have constructed mental models. The purpose of this study was to investigate the impact on students' mental models of light as a result of a teaching sequence where the students studied the particle and wave models of light.

This paper reports on one aspect of the third year of a longitudinal case study of six Year 10 students' understanding of optics with the adoption of a constructivist teaching and learning strategies in three separate teaching stages over a three-year period. This aspect relates to an investigation of the students' mental models of the nature of light during their 12th year of schooling. The researcher acted in the dual roles of teacher and researcher. The longitudinal nature of the study allowed for the tracking of the students' understandings of several key concepts of geometrical optics over the first two years. The students' understandings of geometrical optics then formed the basis of exploration of their mental models of the nature of light in addition to their views of the nature and function of scientific models over the students' views of the nature and function of scientific models is not reported in this paper. During the Year 12 teaching stage the students studied physical optics and quantum ideas and engaged in discussions about the role of models in science. The pertinent research question relating to this part of the study was, 'What mental models do students have about the nature of light?'

Methods

The research design relating specifically to the exploration of the students' mental models of light centered on three semi-structured interviews and three questionnaires administered over a period of several months in the students' 12th year of schooling. The teacher/researcher also made classroom observations. The first two interviews occurred before the teaching stage and the third interview was held after the teaching stage. The questionnaires were administered before and during the teaching stage.

The first of the interviews explored the mental models of the nature of light constructed by the students in explaining situations as they related to the key concepts addressed in the first two years of the study. The data from this interview revealed three different models used by the students to explain various phenomena of light. These models then formed the basis of a questionnaire that was administered to the students some three months after the first interview. It contained questions that centered on students selecting an appropriate model, with reasons, for different phenomena of light. The interview and questionnaire data for each student was fed back to them in the second interview. Students were asked about their own models and their thoughts about opposing models. The final interview occurred one month after the teaching stage and probed the students' mental models of light in the context of several phenomena of light.

The first part of the Year 12 teaching stage involved eliciting and discussing the students' mental models of the nature of light on the basis of their responses to the questionnaires. For the rest of the Year 12 teaching stage the different scientific models, including the student-generated mental models, were evaluated in terms of their scope, and predictive and explanatory power in explaining various phenomena of light already met in Year 10 and Year 11 as well as new phenomena. The new phenomena included diffraction and interference effects of light, and the photoelectric effect. Difficulties encountered with any of the scientific or student's mental models in the explanation of specific phenomena of light were discussed and possible changes to models were explored. The opportunity was given for students to alter and revise their existing mental models as well as invent new ones.

Results

During Year 10 and 11 the students had expressed a high level of confidence in having a scientific understanding of several key concepts of geometrical optics that they showed on many occasions (Hubber, 2005). However, they had developed a mental model of light that related to their understanding of rays, which was inconsistent with scientific understanding. They believed that rays are actual constituents of light, conceptualized as continuous streams of material that can vary in size depending on the strength of the ray; the brightness of the light is then related to the strength of the ray or its concentration of number.

When asked about the nature of light at the beginning of Year 12 all students had maintained rays as part of their mental models of light but three of the students now believed that rays were representations of light rather than actual constituents (refer to Table 1). There was evidence of three distinct models described as the standard ray model, beam ray model and particle ray model. The standard ray model matches the scientific view of a geometric construction, in the form of an arrow, to show the direction of light propagation represented as water waves, the beam ray model represented light as continuous streams of material, while the particle ray model represented light as particles. When these models were presented to the students to explain various phenomena of light there was variation in their preferred models (refer to Table 2).

During the Year 12 teaching stage the students compared and tested their own personal models of light against the scientific models for different light phenomena. This resulted in each student achieving a scientific understanding of the nature of light in terms of the application of the particle scientific model or the wave scientific model to explain various light phenomena. Table 3 shows their preferred models to explain various light phenomena. The students were confident in using either particle or wave ideas depending on the phenomenon to be explained and were aware that their mental models of the nature of light had changed over the teaching period.

The students' mental models had changed from conceptualizations of a ray to that of a photon. Just as there was variation in the mental models of a ray there were also quite subtle differences in their mental models of a photon (refer to Table 1). Four of the students had constructed hybrid models whereby photons acted separately to account for particle like behavior of light but acted collectively in waves to account for wave-like behavior.

Conclusions and Implications

This study found that students construct their own mental models of the nature of light, some of which are different to the scientifically acceptable scientific models, before and during the teaching of the scientific models. Prior to Year 12 the students held a mental model where rays were actual constituents of light but at the same time were able to successfully account for a whole range of geometrical optical behaviour. By the end of the Year 12 teaching sequence the students could successfully account for different optical phenomena in terms of a particle or wave model of light. That is, they chose either a particle idea or a wave idea to explain a specific light phenomenon (refer to Table 3). However, in thinking about the nature of light, the students had constructed a hybrid model of light that related to the photon. This model had the photon with both wave and particle characteristics. One could argue that the students achieved a scientific understanding of light behaviour despite holding a mental model of light which varied from the scientific models. On the other hand, one may view the students' understanding of light as limited as it does not contain a scientific view of the nature of light.

The construction of hybrid models raises an issue related to the students' understanding of the nature and function of scientific models. Alan had a view that light is actually composed of photons which he replaced from a model that he and the other students had, that light consists of rays. Alan's thinking is consistent with a 'naive realist' epistemology (Nadeau & Desautels, 1984), where models are direct copies of reality. On the other hand the other students changed to a more sophisticated epistemology where their hybrid photon models are considered representations of reality. However, three of the students, Christine, Evan and Frank, melded two quite distinct ideas into the one model, and extracting a particle idea when thinking about individual particle-like photons and a wave idea when particle-like photons act in great numbers. Such a thinking reflect a view that models are representations of reality, rather than a more scientific view that models are representations of ideas, or concepts, one has about reality. Beth's hybrid model maybe considered closest to the scientific view of the nature of models as her 'wavicle' view of a photon (refer to Table 1) was considered as a convenient image to think about light either as a particle or a wave.

In teaching of the scientific models of light, care needs to be taken to make clear distinctions between the models, highlighting the view that they represent different ideas. Therefore, the teaching of the scientific models should occur at the same time the teaching of the nature and function of scientific models occurs. In respect of the teaching of light, the teaching about the nature and function of scientific model scientific models should occur at the same time geometrical optics is taught as the ray scientific model is used extensively. In addition, there is a need to explicitly focus on students' mental models as part of the pedagogical strategies adopted in optics as a mental model of light that was formed prior to or on entering school may be guiding students' thinking about the nature of light.

*Student	Mental Models of the Nature of Light						
	During Year 10 & 11	During Year 12					
		Before Year 12 Teaching Stage Following Year 12 teaching Sta					
Alan	Light is composed of rays	Light is composed of rays that are continuous streams of material	Light is composed of photons that are particle-like in nature but act as a wave or ray in great numbers.				

Table 1 Students' mental models of the nature of light

Beth	Light is composed of rays	Light is composed of rays that are streams of particles	Light acts like waves or particles. Photons are theoretical entities that can be imagined as a 'wavelet' which metamorphose into particles or waves depending on which of a particle or wave idea is required to explain a specific phenomenon.
Christine	Light is composed of rays	Light acts like waves or particles	Light acts like waves or particles. Light is composed of theoretical particle entities called photons with electrical characteristics that act like a wave in great numbers.
Danielle	Light is composed of rays	Light acts like waves or particles	Light acts like waves or particles. The particles are theoretical entities called Photons. Waves are like water waves.
Evan	Light is composed of rays	Light is composed of rays, called ray beams, which are continuous streams of material	Light acts like waves or particles. Light is composed of theoretical entities, called photons, which have both particle and wave characteristics.
Frank	Light is composed of rays	Light travels like waves in a direction shown in diagrams by arrows called rays	Light acts like waves or particles. Light is composed of theoretical particle-like photons, which have electrical characteristics and behave as a wave in great numbers.

Note: * Pseudonyms have been used for students in this study.

Table 2 Students' preferred model(s) for various light phenomena before the Year 12 teaching stage

	Student						
Phenomenon	Alan	Beth	Christine	Danielle	Evan	Frank	
Light spreads out in all directions from the light source.	Beam	Particle	Beam	Beam	Beam	Wave	
Each point on a luminous object emits light in all directions.	Beam	Particle	Beam	Beam	Beam	Wave	
Light bends and slows down in going from air into glass.	Beam	Particle	Wave	Beam/ Wave	Beam	Wave	
White light is composed of different colours.	Beam	Particle	Wave	Wave	Beam	Wave	

	Student							
Phenomenon	Alan	Beth	Christine	Danielle	Evan	Frank		
Light spreading out from a luminous object	Particle	Wave	Wave	Wave	Particle	Wave		
Isotropic emission of light from each point on a luminous object	Particle	Wave	Wave	Wave	Particle	Wave		
Specular reflection	Particle	Wave	Wave	Wave	Particle	Particle		
Diffuse reflection	Particle	Wave	Wave	Wave/ Particle	Particle	Particle		
Colour	Particle	Wave	Wave	Wave	Particle	Wave		
Rectilinear propagation	Particle	Wave	Particle	Wave	Particle	Particle		
Refraction	Wave	Wave	Wave	Wave	Particle	Wave		
Photoelectric effect	Particle	Particle	Particle	Particle	Particle	Particle		
Diffraction	Wave	Wave	Wave	Wave	Wave	Wave		

Table 3 Students' preferred model(s) for various light phenomena following the Year 12 teaching stage

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Conceptual understanding of the Maxwell wheel motion

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Abstract

The concrete experience with the yo-yo wheel motion can become a good starting point for the student understanding of the concepts of rotational motion.

The first step is to gain information about student's knowledge in the field of rotational motion of flywheels with the help of conceptual question test. The results of the test, administrated to University students after the Mechanics course presented, show rather low level of understanding of the concepts of rotational motion.

In order to help in better understanding of the rotational motion concepts there is an inquiry based laboratory work designed for students. The aim of this laboraties is to study the rotational and translational motion of the Maxwell wheel in order to describe and analyze the kinematics and dynamics of this kind of motion. Students measure and analyze the position, velocity and acceleration of the moving wheel with the help of MBL tools. Furthermore, they determine the force acting on the wheel at the lowest point and study the motion from the energetic point of view. They discuss the mentioned problems with their peers in order to draw their predictions into the working sheets. After the measurement they compared the gained results with their predictions.

The next part of the measurement is devoted to the study of the motion of two Maxwell wheels with the same mass but different moment of inertia. Their predictions can be compared with the results of real measurement or videomeasurement and the conclusions are presented. There are some additional problems to solve, i.e. Is there any final speed in case of a very long string or the speed will be increasing unlimitedly? The increase in moment of inertia leads to the decrease in acceleration of the wheel. Is there any limit in acceleration decrease? Is the force acting at the lowest point the same for the wheels of the equal mass and different moment of inertia? What is the length of the string for which the string tore apart assuming we know the breaking point of the material?

In order to evaluate the effect of the labwork on student knowledge the students answer a post-test about two weeks after the teaching.

Everyday experience and students first concepts

Everyday life offers a lot of occasions to observe the behavior of objects that present different physical phenomena. Popular child toy yo-yo wheel is an example of rotational motion of a flywheel caused by the presence of the gravitational force. This concrete experience with the yo-yo wheel motion can become a good starting point for the student understanding of the concepts of rotational motion. From the yo-yo wheel we can go on to the description of flywheels motion, e.g. to the simplified yo-yo used in the introductory physics lab called the Maxwell wheel.

Showing and presenting the physical factors influencing the objects functioning in the process of teaching can help in:

- Linking the already known and new students' knowledge.
- Developing of physical thinking from concrete to abstract.
- Increasing students' interest in physics.
- Presenting and understanding of the use of physical knowledge in everyday life.

Conceptual test questions about the rotational motion

In order to get information about the level and extent of students' knowledge about the rotational motion of a flywheel we prepared a conceptual test. Students answer a set of 11

multiplied choice questions in about 10-15 minutes. The test is answered after the mechanics course before the laboratory work realized in MBL. The test items are aimed at:

- Description of the wheel velocity during the downward motion
- Description of the wheel angular velocity during the downward motion
- The lowest point of the motion
- The reason of the impulsive force at the lowest point of the motion
- The reason of the wheel's upward motion
- The influence of the wheel's mass on its speed
- The influence of the wheel's size (without any change in shape) on its motion
- The influence of the mass distribution (without any change in mass) on the wheel's motion

The test results show a low level in understanding of the principles of the flywheel motion. The most important points of misunderstandings are as follows:

- Understanding of two kinds of motion (translational and rotational).
- The influence of the moment of inertia on the wheel's rotational and translational motion.
- Understanding of the origin of the impulsive force acting during the change in direction of the wheel's motion.
- The influence of the mass distribution on the moment of inertia.

Theoretical model of the Maxwell wheel motion

The Maxwell wheel consists of a disc of radius R having an axis of radius r (with $r \ll R$) suspended from a fixed frame by two strings of equal length, which are wound around the axis (fig.1). There are two possible models describing its motion available. One is based on the energy consideration and the other one takes into account the fundamental laws of translational and rotational motion.



If we let the wheel fall from a height h, and the potential energy U(x) is referred to the equilibrium position (U = 0 at x = 0), the system total energy E at the start (x = h, v = 0) is E = mgh. The force F responsible for the acceleration of the wheel is the gravitational force, which can be considered to act on the centre of mass of the body. During the fall the potential energy transforms into translational kinetic energy $E_t(x)$ and rotational kinetic energy $E_r(x)$. The energy of rotational motion is proportional to the moment of inertia of the wheel. Assuming negligible dissipation, we may write therefore:

$$E = U(x) + E_t(x) + E_r(x)$$
$$mgh = mgx + \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

where m is the Maxwell wheel mass, I the moment of inertia and the angular velocity. Translational and rotational motions are not independent; the angular velocity is related to the linear velocity by:

$$v(t) = r\omega(t)$$

Solving with respect to the velocity, we get a relation similar to that for the velocity of a free body falling from height h:

$$v(x) = \sqrt{\frac{2g(h-x)}{1+\frac{I}{mr^2}}} = \sqrt{2\frac{g}{k}(h-x)} = \sqrt{2a(h-x)}$$

showing that the acceleration of the center of mass is:

$$a = \frac{g}{k} = \frac{g}{1 + \frac{I}{mr^2}}$$

The same result can be gained using the dynamical equations describing both motions of the wheel. The net force acting on the wheel causes it to be accelerated according to the second law of motion

$$mg - F_t = m.a$$

where F_t is a sum of vertical string tensions acting upwards on the wheel. The dynamical equation describing the rotational motion of the wheel is as follows:

$$T = F_t \cdot r = I \cdot \varepsilon = I \cdot \frac{a}{r}$$

where T is a net applied torque and ε is an angular acceleration of the rotational motion. Combining these two equations we finally get the same expression for the acceleration of the wheel.

From the result for the wheel acceleration it can be seen that the increased moment of inertia results in decrease in acceleration of translational motion. For $r \ll R$, the moment of inertia, I, of the wheel is a good approximation to that of the disc ($I \approx mR^2/2$), and therefore the predicted acceleration is

$$a \approx \frac{g}{1 + \frac{R^2}{2r^2}} \approx g \frac{2r^2}{R^2}$$

The elastic energy of the stretched string has not been taken into account. During upward and downward motion the total energy decreases. At the lowest point of the motion there is a change of linear velocity sign (passing through zero) while the angular velocity remains approximately constant. There must be a force the string acts on the wheel. As a reaction there is a force that the wheel acts on the string that we can feel during the velocity change at the lowest point.

Teaching method

In order to help in better understanding of the rotational motion concepts there is an inquiry based laboratory work designed for students. The aim of this labwork is to study the rotational and translational motion of the Maxwell wheel in order to describe and analyze the kinematics and dynamics of this kind of motion. Students working with their peers can realize two types of measurements depending on the apparatus available. They can do a real-time measurement on the Maxwell wheel with the help of an ultrasonic motion detector and a force sensor or a video measurement on a video clip already prepared for the students (fig.2). After collecting the data the analyzing procedure is the same in both cases. Measuring the position of the wheel and the string tension in the case of real-time measurement students analyze the results according to the instructions in their working sheets creating velocity vs. time and acceleration vs. time diagrams from the position vs. time diagram (fig 3).

Fig.2 Video measurement realized in IP COACH system.



Fig.3 Position vs. time graph, velocity vs. time graph, acceleration vs. time graph, string tension vs. time graph gained from the real-time measurement.



Furthermore, they can determine the force acting on the wheel at the lowest point with the help of the acceleration counted from the change in velocity. The analysis can be followed by the energy balance of the motion (fig.4). They discuss the mentioned problems with their peers in order to draw their predictions into the working sheets. After the measurement they compare the gained results with their predictions and with the theoretical results (fig.5).

Fig.4 Potential energy vs. time graph, translational kinetic energy vs. time graph, rotational kinetic energy vs. time graph, total energy vs. time graph gained from the real-time measurement.



The next part of the measurement is devoted to the study of the motion of two Maxwell wheels with the same mass but different moment of inertia. Their predictions can be compared with the results of real measurement or video measurement and the conclusions are presented. In order to evaluate the effect of the labwork on students' knowledge the students answer a post-test about two weeks after the teaching.

Fig. 5 Theoretical model of the Maxwell wheel motion (left) and the velocity vs. time graphs (theoretical and experimental).



Student's worksheets

All the instructions for the students are presented in the working sheets. There are questions to answer, discussions, prediction sheets and conclusion sheets prepared for the students to fill in. Students gradually discover the properties of the flywheel motion and the results gained experimentally can be compared with the theoretical results (fig.5). After the labwork we can verify the level of their knowledge with the help of complementary questions, such as:

- Is there any final speed in case of a very long string or the speed will be increasing unlimitedly?
- The increase in moment of inertia leads to the decrease in acceleration of the wheel. Is there any limit in acceleration decrease?
- Is the force acting at the lowest point the same for the wheels of the equal mass and different moment of inertia?
- What is the length of the string for which the string tore apart assuming we know the breaking point of the material?

Conclusion

The designed labwork aimed at the study of the behavior of a simplified model of the wellknown child toy yo-yo (Maxwell wheel) realized with the help of MBL tools (PC with interface and sensors or videoanalysis) offers students to realize inquiry-based learning in MBL. Furthermore, it allows an opportunity to compare theoretical results with the ones gained from the experiment. The labwork itself is supported by the worksheets with the instructions that should help students to concentrate to the most important points of the wheels' motion to study and analyze. We are persuaded that this way of teaching and learning can surely help in better understanding of the presented phenomena and in changing the misunderstandings and misconceptions the students have. In the future we are planning to continue in this work in order to help students in better understanding of the physical phenomena that are proved to be difficult to understand in standard physics courses.

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Understanding basic physical concepts – which? The Modeling of Real World Phenomena Based on Laws of Physics

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Abstract

In the process of teaching students basic concepts of physics, it turns out that the first problem is not the introduction of new concepts but the underlying use of physical quantities and the formulation of relations between them. While it is clear that in the teaching process a careful introduction of new concepts is necessary, in an attempt to convey to students the right "feeling" about their meaning, less emphasis is given to formal manipulations of physical quantities as mathematical entities which are needed in practical problem solving.

Our research's goal was to determine which are the main problems and obstacles that students encounter in acquiring a working knowledge of physics. A study was conducted among freshmen who had combination majors mathematics-technology, chemistry-biology and biology-home economics, and the fourth-year students who had combination majors physics-technology and physics-chemistry. The results of this study show that the weak links are often the "accessory" and "subsidiary" knowledge needed in addressing physical problems.

Not only is a proper approach needed in teaching, but maybe additional training is necessary for teachers in order to avoid, in the teaching process, a mechanical use of formulas leading to a superficial knowledge without a satisfactory understanding, also in the sense of existing passable (open) channels between various pieces of knowledge. Our intent is not to go deeper into explanations of the topics of the physics curriculum, but to give students more time to gain a general view of the structure of interwoven pieces of knowledge and to consolidate their knowledge.

1. Introduction

Even though physics, as a scientific and technical discipline, enjoys a considerable reputation in public, it seems that the teaching of it has become rather unpopular at all levels, from K-12 to college. From elementary school on, students, except for a small minority which has a particular talent for physics, find physics more or less unnecessary and physics classes difficult or useless.

In the present article we are addressing the general education of physics and not the physics for physics majors.

The basic question, asked by students from the beginning of their physics classes, is what to do with physics. They don't have a clear picture about what to expect from physics instruction and where to place physics in a broader context. At the same time they feel that physics is a "high" scientific discipline, inaccessible by ordinary people. An imitation of a "scientific" behavior and acting "like a scientist" seems to them exaggerated and they are not eager to imitate it, because they would feel ridiculous.

On the other hand the teachers of physics feel that the lack of interest in physics is not deserved, that not enough time is given to the teaching of physics, and that it should be broadened and intensified. Especially during the implementation of the Bologna reform it is clear that in college-level science programs not much time and emphasis will be given to physics. On the contrary, the teaching of it will have narrower time frame and will face greater competition from other (for example general education) subjects.

In such conditions it is necessary to investigate in what ways can the teaching curriculum be made more attractive and successful not only for students who are particularly interested in physics, but also for a broader audience. Therefore, it is of basic importance to determine what are the basic physics content knowledge and skills that students should learn to master. Searching for an answer, we encounter different levels of knowledge and content. Distinguishing them is important in the structuring of content and methods of teaching (Glynn and Duit, 1995).

To start with, we can state that the knowledge of phenomena and skills in measuring procedures represent only the outer shell of what students should learn about physics. Maybe

we could, somewhat pretentiously, say that the basic purpose of the teaching of physics, especially at below-college level, and to non-physics majors, is the modeling of the workings of the real world and the creation of the scientific part of the view of the world. This kind of knowledge should not be reserved exclusively for "professional physicists", but should rather be the main objective of the physics instruction from its beginning. This just means that in studying phenomena we focus more on the underlying structures and principles of the world than their manifestations.

In the following sections we present what we consider to be the essential elements of the teaching of physics, if it is to successfully present physical explanations of nature.

2. Phenomena, concepts, quantities and connection

The basic physics instruction usually starts with a description of familiar phenomena (accompanied by suitable experiments). Based on these phenomena general laws of physics are discovered. Students learn these laws, use them to understand other phenomena, and solve related problems.

Here we encounter a basic sequence of steps leading toward "knowledge":

phenomena \rightarrow concepts \rightarrow definitions \rightarrow (feeling) \rightarrow manipulation \rightarrow problem solving.

Each step should be accompanied by the important factor of understanding (Feynman, 1966).

The scientific observation of phenomena is a systematic perception of the real world. It demands some capacity for registering of those aspects that are the most essential for a particular phenomenon. Based on observations of the real world basic concepts are created. These are mental constructs, general concepts that we create (possibly with help of others), 'basic building blocks', 'atoms' or 'components' of a theory. Often we don't fully understand basic notions and often they are difficult to explain. Nevertheless, they are the starting points of any theory and are, despite not being always completely clear, important tools in problem solving. Every theory creates 'its own' concepts. A change of concepts as mental elements changes theories. In turn, changes of theories cause revisions of the concepts.

Directly from the concepts definitions are formed. They formulate concepts in a precise way, listing all their essential properties and characteristics. While in the formulation of concepts often no precise formulation is given, definitions are as a rule given rigorously. As a consequence, in more demanding definitions, 'rote memorization' often replaces understanding. All physical quantities (e.g. position, coordinates, velocity, acceleration, kinetics, energy, temperature, heat, electric current, etc.) are notions, precisely determined through definitions, and are the result of mental forms created by observation and quantitative treatment of physical phenomena.

A good 'feel' for natural phenomena and as a consequence an instinctive element of an understanding of how the nature is functioning, follows from a good understanding of concepts and definitions. On this basis we can understand and appreciate, at the first glance controversial, so called Wheeler's first moral principle (Taylor and Wheeler, 1992): "Never make a calculation until you know the answer!" His further comment: "Make an estimate before every calculation, try a simple physical argument (symmetry! invariance! conservation!) before every derivation, try the answer to every paradox and puzzle. Courage: No one else needs to know what the guess is. Therefore make it quickly, by instinct. A wrong guess brings the refreshment of surprise. ..." Let us add that a good 'feel' for the workings of phenomena is of essence also for a good feel in establishing a relationship to physics.

The next step is to a greater degree of a technical nature. It is a "manipulation" of concepts and definitions, or of introduced physical quantities. In physics curriculum students learn how to treat phenomena "quantitatively". Already Galileo Galilei believed that all phenomena can be understood on the basis of general laws of nature which can be formulated mathematically. Laws of physics are just quantitative relations between different physical quantities. (For example, the Second Newton's Law connects the acceleration of a body to forces acting on the body.) If we treat physical quantities as abstract mathematical quantities, we can, through mathematical operations, "simulate" events of nature and, by using laws of physics and appropriate initial and boundary conditions, calculate quantities of interest. (We are aware of the fact that the "logic of empirical statements is not the logic of mathematical

theory". Still, it seems reasonable to consider physics, especially from the educational point of view, as "the science devoted to discovering, developing and refining those aspects of reality that are amendable to mathematical analysis", see Ziman (1978).)

This brings us to the last step, to problem solving. A physics problem or a question means that out of given data (or data obtained by measurements) we are expected to find certain other quantities. A solution means that we arrive from data to quantities requested in a problem or a question. We have to find relations between known quantities and the unknown quantities that the problem asks us to find. This is done through the use of laws of physics which are, as we stated earlier, relations between different physical quantities. In simple problems connections are simple and can be written in "one line" or with "one formula". More demanding problems, though, require several steps, with several lines and formulas, in order to arrive from the data to desired quantities. Harder problems require clearer picture and understanding of the content of laws of physics on which the solution is based. Solving a problem therefore means a search for quantitative connections between data and desired quantities. Those connections are written mathematically as equations.

3. Which are basic physical concepts?

Usually the teaching of physics means that students get acquainted with basic notions appearing in all standard main areas of physics, starting with so called "classical" physics (without the relativity theory). These are mechanics, thermodynamics, electricity and magnetism, light and optics. Then (within time constraints) modern physics follows. It includes the relativity theory and some basics of quantum mechanics.

Even though the treatment of these at no stage of school curriculum goes in depth (except for physics majors), it is clear that a presentation of basics alone requires a significant number of suitable concepts and definitions. At that it is important to realize that most of the time the problem is not an intuitive understanding of notions that students are mostly familiar with from everyday life, like path, speed, acceleration, temperature, heat, electric current and voltage, etc. The problem is to create an overview of all different notions and a realization that it is details which are of decisive significance for the correctness of a certain idea and its treatment. For example, for most students, it is not easy to distinguish between velocity and speed (which is the magnitude of the velocity), displacement and path, uniform motion and uniform rectilinear motion (which is the only unaccelerated motion), temperature and heat, etc. The question is whether under conditions of severely limited time available for instruction it makes sense to insist on the mentioning of all the topics which are (usually) part of school curricula and presented in a majority of textbooks (like for example Serway, 1996).

We believe that the goal of physics instruction is more than a presentation of all topics of the classical and modern physics a creation of a "physical" view on the nature. Under "physical" view we understand an interest in structures of reality as they stem from laws of physics, rather than specific facts about a multitude of specific phenomena. It is quite clear that it is impossible to present all specific findings about the nature as they have accumulated until now through scientific research. It is possible, however, to create an overview over what is happening in nature, i.e., to group natural phenomena according to laws of nature which determine the course of certain phenomena (Feynman, 1966).

When we talk about structures we think about functional connections between quantities and relationships between them. This makes sense, since we saw that laws of nature occur as functional connections between physical quantities. Equality of structures of course means the same underlying mathematical description which does not depend on the specific nature of respective quantities. Equality of structures also means the equality of equations and therefore their equal solutions. As R. P. Feynman (1966) put it: "The equations for many different physical situations have exactly the same appearance. Of course, the symbols may be different—one letter is substituted for another—but the mathematical form of the equations is the same. This means that having studied one subject, we immediately have a great deal of direct and precise knowledge about the solutions of the equations of another."

The recognition of the fact that everything occurring in nature happens in accordance with a few (relatively) simple laws of nature which are obeyed by all phenomena in nature is of paramount importance for our world picture: "Nowadays, as superstitions are again spreading, it is important to show in schools, without religious fervor, the long-reaching significance and the universal validity of laws of physics. The end of an introduction to mechanics is a wonderful opportunity to do that. A child does not grasp immediately that there could be laws of physics that are valid uncompromisingly. However, the most basic law is the fact that there are no magic tricks in nature. Some people do not want to believe even that." (Kuščer, 1979)

Thus, in a multitude of phenomena, structures are created based on laws of physics, which allow a grouping of seemingly very different phenomena, which can be distinguished and yet grouped together on the basis of the structural understanding about the functioning of nature. The same Newton's law, for example, can explain such different phenomena as the motion of the planets around the sun, and the sound. Thus high-level synthesis knowledge is formed.

This, of course should not be applied in the same way for all levels of the teaching process. At lower levels it is important that children learn how to systematically observe nature and to establish a connection between physical concepts they encountered, and to receive, during physics instruction, a more precise formulation and a wider knowledge. First, familiarizing with phenomena prevails over the recognition of structures. At higher levels it becomes more and more important to discover structures of nature, i.e. connections between diverse phenomena which obey the same laws of physics.

If we decide that the goal of physics instruction is to create clear structures which contain all phenomena (that we are able to explain), a somewhat different approach to teaching offers itself, i.e., to treat phenomena based on the similarity of laws that govern them. This means that, while it is important to establish a familiarity with some set of basic pieces of phenomenological knowledge, it is important to establish interconnections between them rather than to enlarge that set.

These connections occur inside physical concepts, but they also need to reach outside of the realm of physics. When we use mathematics in the quantitative treatment of physical phenomena, we also have to understand structures. For a "simulation" of a phenomenon we use mathematical manipulation of physical quantities that stem from equations that connect them. Thus, in the teaching of physics it is important to establish nets of connections between concepts and quantities. "Connectivity", the number of connections, is more important than the number of concepts alone.

4. Difficulties

Giving a questionnaire to students of combined majors mathematics-technology, chemistrybiology, biology-home economics, and mathematics-computer science, we wanted to find out where students encounter the greatest difficulties in their use of the knowledge of physics, i.e., when they are solving problems. We wanted to see where are "bottlenecks" and where can the situation be improved. Among the most frequent reasons for problem solving blocks the following were listed.

- 1. poor knowledge of mathematics (75 %)
- 2. students don't find the "right formulas" for the given problem (73 %)
- 3. the inability to "set up equations", i.e., mathematically formulate the relationships between physical quantities that appear in the problem (67 %)
- 4. a lack of knowledge of the area of physics that appears in the problem (65 %)
- 5. a lack of knowledge of concepts that appear in the problem (63 %)
- 6. a lack of understanding of notions that appear in the problem (41 %)
- 7. a lack of understanding of "formulas", i.e., "why should two quantities be related by such a formula" (21 %)
- 8. a lack of interest in physics (13 %)

From the answers it is apparent that students feel that the greatest difficulties lie in the lack of knowledge of mathematics, which includes, besides a lack of purely mathematical skills, an inability to *translate* connections and relationships, which they know how to describe in words, into a mathematical form, i.e., into equations

Here it is clear that we don't always deal with a lack of knowledge of mathematics, but rather with an inability to *use* mathematical knowledge, which they *do* have in purely mathematical context also in non-mathematical environment. Mathematics does enable one to solve physics problems operatively. However, mathematical manipulations alone are far from being sufficient to solve them. For example, 75 % of students correctly calculated the extremum of the function $y(x) = ax/(b + x)^2$. A week later they found that an electrical device in a circuit uses power $P = RU_g^2/(R + R_n)^2$. When asked when the use of power was maximal, only 17 % answered correctly.

The situation is similar when "setting up equations". Virtually all students know the meaning of proportionality – if the variables y and x are proportional, then y = kx, where k is the coefficient of proportionality. When asked to describe the motion of a boat which comes to a stop in such a way that its acceleration is proportional to its speed, only 17 % of students were able to write the correct relation.

Therefore it is of fundamental importance that the knowledge acquired in any subject is not limited only to the subject itself. To this aim, an emphasis on connections between physical notions and quantities, and mathematical procedures is very important in physics instruction.

But it brings certain difficulties and the following are some examples.

1. Newton's Law of gravitation and Coulomb's Law. The gravitational force between two particles (with masses m_1 and m_2 separated by a distance r) is given by Newton's Law, $F_g = Gm_1m_2/r^2$; the magnitude of electric force between two charges (q_1 and q_2 at a distance r) is given by Coulomb's Law, $F_e = k_e q_1 q_2/r^2$. Both laws have the same functional form and similar consequences (not identical, as there is only one type of masses and two types of charges).

It is interesting that the introduction of the gravitational law in the framework of mechanics does not cause any difficulty: the law is totally 'acceptable' and understandable. The same is true for Coulomb's Law presented in the framework of electricity. However, there is lack of understanding or acceptance if Coulomb's Law is presented together with the gravitational law (after all, say the students, the material "unjustifiably" reaches into a material that has not been "covered"). Similarly, the same happens to the gravitational law when it is presented along with Coulomb's Law (since the students have "already forgotten" the material from mechanics to which they are entitled after certain time). This is particularly clear when introducing the analogy between the electric and gravitational field. While the introduction of electric field (E) via the equation $\mathbf{F_e} = q\mathbf{E}$ is "acceptable" and does not pose problems, students are not at all ready to view, in the analogous equation $\mathbf{F_g} = m\mathbf{g}, \mathbf{g}$ (the free-fall acceleration) as the "gravitational field". In this case it is clear that students view the new manifestation of the same notion as something completely new. This means that one of the principal goals in physics instruction – the ability to recognize structures, as opposed to the knowledge of separate phenomena – is not achieved.

2. The slowing down of a boat and the discharging of a capacitor. A kinematics problem asks how a boat slows down if the deceleration is proportional to the speed. The solution is a speed that decreases with time exponentially. After finding the solution to this problem, students were asked a similar question in a different context: what was the current in a circuit with a capacitor and a resistor, if the time derivative of the current was proportional to the current. Virtually no help came from the analogy between the two cases.

3. Question: The figure below shows two parabolas. What phenomena can be represented by the two graphs? The given answers involved many quantities for which we can only say that they change, but certainly not as a quadratic function. For example, the answers included the path of a uniform motion, the charging and discharging of a capacitor, the warming and cooling of water.



As it is clear that the students know a lot about "mathematical" parabolas, the answers clearly show that no connection is made between their concept of the mathematical world and any other mental environment.

5. Conclusions

The physical picture of the world and the "physical" approach to problem-solving based on the recognition of structures, rather than single phenomena, i.e. manifestations of the underlying structures, enable students to confront problems of any kind (not just problems in physics) in an analytic-synthetic way. Stated simply (Feynman et al, 1966), "The same equations have the same solutions." A simple consequence of this fact is that the recognition of structures makes it possible to construct *models* (which are formally describable by equations). A few models may cover many different phenomena from many different contexts. The structural knowledge obtained at the physics instruction is therefore helpful in solving any problem with the same underlying structure.

A model is a simplified (and therefore tractable) representation of a restricted feature of the real world. The modeling of natural phenomena is very important, both in science and in education. However, it has not the same importance in all instances. For example, when introducing and describing simple phenomena (like rectilinear uniform motion), it does not seem necessary to introduce intermediate stages in terms of "models" which are sometimes more complicated that the phenomenon itself. In such cases, "modeling" may even obscure a clear and simple picture that students already have about a phenomenon. (It may still be appropriate to introduce models about simple phenomena as prototype-models.) When describing complicated phenomena, the use of models is unavoidable: they convey a simplified, yet both acceptable and tractable qualitative information.

Therefore, in order to make the instruction more efficient, it is necessary to reduce the number of separate topics ("non multa sed multum"), and at the same time keep stressing the "underlying unity of nature" i.e. the similarity of rules, according to which sometimes apparently different phenomena behave. The same rules of course mean analogous behavior.

It seems reasonable to regard the instruction of physics as a modeling, not only of single phenomena, but of the physical reality as whole. The scientific part of the "view of the world" is nothing but a "meta-model" of the fabric of reality.

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Introducing mechanics by exploiting core causal knowledge

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Abstract

This paper concerns an 'in principle' outline of an introductory mechanics course. It is based on the argument that various uses of the concept of force (e.g. from Kepler, Newton and everyday life) share a common explanatory strategy, which has its basis in core causal knowledge. The explanatory strategy consists of (a) the idea that a force causes a deviation from how an object would move of its own accord (its *force-free* motion), and (b) an incentive to search, where the motion deviates from the assumed force-free motion, for recurring configurations with which such deviations can be correlated (*interaction theory*). Various assumptions can be made concerning the force-free motion, thus giving rise to a variety of specific explanations. Kepler's semi-implicit intuition is *rest*, Newton's explicit assumption is *uniform rectilinear motion*, while in everyday explanations a diversity of highly pragmatic suggestions can be recognized.

The idea is that the explanatory strategy, once made explicit by drawing on students' intuitive causal knowledge, can for students be made to function as a kind of advance organizer, as a general scheme that they know needs to be filled in but do not yet know how to fill in concretely for scientific purposes.

Introduction

This paper is about a new approach to introduce mechanics for academically streamed students of about 16 years of age. What we think is new about our approach, at least in emphasis, is our aim to provide students with *content-based outlooks* on what they are going to learn and why. We call our approach *problem posing*. The reason for this name is that one would have a clear case of students having a content-based outlook on what they are going to learn and why, if one could bring them into a position in which they themselves come to pose the main problems they subsequently would be going to work on (Klaassen, 1995, chapter 5; Lijnse & Klaassen, 2004).

We also aim to base our approach on a proper analysis of the relation between where students are (common sense) and where we want them to be (science). With respect to this relation we claim that explanations of motion, both from common sense and from science, can all be seen as fillings-in of the same basic structure, which has its basis in core causal knowledge. Differences between the various explanations are partly anchored in distinct explanatory interests.

Our idea is that the basic structure of explanation of motion, which we claim students command, at least implicitly, could for them be made to function as an *explicit directive guide* in learning about explanation of motion—as a kind of *advance organizer* (Ausubel, 1968). To the extent that we succeed in this, students can indeed be said to be provided with a content-based outlook on what they are going to learn and why.

The basic structure of explanation of motion

In this section we somewhat elaborate the claims,

- that explanations of motion, both from common sense and from science, can all be seen as fillings-in of the *same* basic structure,
- that this basic structure has its basis in *core* causal knowledge,
- that differences between various explanations of motion are partly anchored in distinct explanatory *interests*.

We refer to Klaassen (2005) for a more elaborate discussion of these points, partly in reaction to influential studies in the science education literature that claim the opposite.

Core causal knowledge

Our ordinary concept of causation is one of "things going on as they are unless interfered with" (Dummett, 1954). Figure 1, a slight adaptation of a cartoon by Gotlib (1970), is a simple illustration of the basic idea.

Fig. 1. Causes produce deviations from things going on as they are.



On the left we see a man taking a stroll. On the right we see the same man having the happiest thought of his life. The two situations are clearly different. Something must have caused the change. The picture in the middle shows what.

Of course, much more can be said about our ordinary concept of causality. In order to explain why not anybody who had an apple fallen on his head subsequently came up with the idea of universal gravitation, for instance, one may wish to distinguish between enabling conditions and trigger events. In order to meet the complaint that much more must have happened than the fall of the apple on Newton's head, one may want to note that our notion of causality is shot through with interests. What is selected as 'the' cause of some event is some feature of the totality of causal factors that particularly interests the explainer. Usually it is something he finds surprising, or that he thinks his audience will find out of the ordinary.

For our purposes, however, it suffices to just point out that causes effectuate *changes of state*. More formally, Descartes put it as follows: "each thing, provided that it is simple and undivided, always remains in the same state as far as is in its power, and never changes except by external causes" (1991, page 59).

Explanation of motion as a species of causal explanation

The picture of causes as effectuating changes of state can also be seen at work in explanation of motion. After all, explanation of motion is a special case of causal explanation. What gets explained are not changes of state in general, but changes of state of motion, and forces effectuate such changes.

A clear example of this can be seen in Newton's construction method. The diagram on the left in figure 2 is taken from the proof of Theorem 1 of Section 2 of Book 1 of the *Principia* (Newton, 1999, page 444). Newton writes: "Let the time be divided into equal parts, and in the first part of the time let a body [...] describe the straight line AB. In the second part of the time, if nothing hindered it, this body would (by law 1) go straight on to c, describing the line Bc equal to AB [...] But when the body comes to B, let a centripetal force act with a single but great impulse and make the body deviate from the straight line Bc and proceed in the straight line BC" (1999, page 444). So the motion BC in the second time interval is compounded of a force-free motion (Bc) and a deviation caused by a force (BV). Newton's assumption for the state of motion, or the force-free motion, is *uniform rectilinear*. Forces cause deviations from such states.

Fig. 2. According to Newton, of its own accord a body would move uniformly straight forward, and forces cause deviations from such states of motion.





Newton

Other assumptions for the force-free motion are also possible. Kepler's assumption, for example, is *rest*, at least for celestial bodies. He writes: "a celestial globe [...] has a natural $\alpha\delta\nu\nu\alpha\mu\mu\alpha$ or powerlessness of crossing from place to place, and it has a natural inertia or rest whereby it rests in every place where it is placed alone" (1995, page 54). Kepler's assumption cannot be refuted on logical grounds. But it does put on him the burden of finding appropriate forces to account for the deviations from his assumed force-free motion.

In order to account for planetary motion, Newton had to find forces wherever the planets deviated from uniform rectilinear motion, and to find the sources of those forces. Newton managed to do so by postulating a gravitational force of the sun on a planet. Kepler, on the other hand, had to find forces for any deviation from rest.



Fig. 3. According to Kepler, of its own accord a celestial body would remain at rest, and forces cause deviations from such states of motion.

In order to make a planet move like the diagram on the left in figure 3 (i.e. in the same way as in Newton's example from figure 2), a force is needed that pushes the planet from A to B, then from B to C, and so on. Of its own accord the planet would stay where it was. Kepler therefore had to find forces that were to drag, so to say, the planets along their paths, and to find the sources of those forces. Kepler managed to do so, as far as his mathematical capabilities allowed (Kepler, 1995; Stephenson, 1994). Of course we are not saying that Kepler's theory of planetary motion has the same scientific status as Newton's (it hasn't), but at least it shows that one can have a serious go at accounting for planetary motion under Kepler's assumption of rest as the force-free motion.

The very same explanatory strategy can be seen at work in the explanation of the man in the street why one has to keep pedaling to maintain speed (figure 4). The simple answer is: because if one stopped pedaling one would gradually come to a stop. In this everyday explanation, the force concerns a personal influence (pedaling) and the force-free motion is the motion of the object without this influence (slowly come to a stop).

Fig. 4. According to the man in the street, if the cyclist did nothing she would slowly come to a stop, but by continuing to pedal she prevents this from happening.



Similarities and differences between the various explanations of motion

There are clear differences between everyday explanations of motion on the one hand, and scientific ones on the other. Everyday explanation, for example, proceeds on a catch-as-catch-can basis and is pragmatically geared to actions we can perform. In particular, there is no need for a uniform assumption concerning the force-free motion. In other situations, e.g. hitting a target with a projectile, another assumption can be made, as long as it is checked by seeing plausible influences to account for the deviations from it.

Scientific explanation, on the other hand, has, amongst other things, a much more systematic character. In the end *every* deviation from the assumed force-free motion has to be accounted for by *exceptionless* force-laws. Due to these rather different explanatory interests, there is hardly any tension between everyday and scientific explanations of motion. Tension *does* arise between Kepler's scheme and Newton's scheme, and in the end Newton superseded Kepler. Just like, in turn, Einstein superseded Newton. Einsteinian mechanics (general relativity) contains yet another assumption for the force-free motion.

Let us now return to the similarities between the various explanations of motion. The similarities can be captured by a two-tier explanatory strategy that is common to all:

- a characterization of force-free states of motion, checked by
- a characterization of force-laws to account for deviations from those states.

This strategy can still be filled in concretely in various ways, thus giving rise to a variety of specific explanations, as the examples from Newton, Kepler and the man in the street illustrate.

What the strategy brings out is that "[t]heories of interaction and the notion of free—or inertial, or geodesic, or 'naturally moving'—particle are intimately connected" (Friedman, 1983, page 121). The strategy does not tell us, however, *what* we ought to choose as forces, states, laws, etc. It only sets *constraints* on such choices. It offers an explanatory *scheme* into which the choices we make must fit. As such, it functions as a *regulative principle* that directs and guides us in investigating the motions of bodies (Nagel, 1979, page 192).

An 'in principle' outline

The conclusion that the basic structure of explanation of motion functions as a regulative principle brings us back to our educational aims. Remember that our aim is to structure the

learning process in such a way that students can *in advance* appreciate each step as *instrumental* to achieving the learning goals. What we now want to suggest is that the basic structure in explanations of motion, and the core causal knowledge in which it is grounded, can serve as an advance organizer, in the sense of dividing the vague initial question of how to explain motion into the instrumental questions of what might be appropriate fillings-in of the various elements of the basic structure.

The idea, therefore, is that students' process of gaining insight in explanation of motion can be supportively directed by a basic structure that students come to appreciate as in principle familiar (as underlying their own explanations), but also as in need of a different filling-in when explaining motion in an unusual (theoretical) frame of mind. In finding appropriate such fillings-in, help can be called in from pioneers on the field of explanation of motion: Kepler and Newton. Students' command of the basic structure will then help them to understand (simplified versions of) the theories proposed by Kepler and Newton *as* alternative fillings-in of the basic structure.

In short, students are expected to recognize various hypotheses as plausible alternative fillings-in of a basic structure that they know needs to be filled in. This is still very much an 'in principle' outline. It will be clear that a lot more needs to be done in order to make it work. It is not enough, for example, that *we* can see students' various explanations of motion as fillings-in of the same basic structure. Somehow they themselves should come to recognize:

- that explanation of motion, as a type of causal explanation, fits into a structure pre-formed by core causal knowledge;
- that fillings-in of this structure may be needed that differ from everyday ones, if one wants to understand why things move as they do in a frame of mind that is not governed by everyday concerns for practical control or satisfaction of mundane needs.

Only then can a motive to search for plausible alternative fillings-in of the basic structure come 'alive' in the sense of forming a real driving force behind the students' learning. Only then can their causal knowledge really function as a supportive and directive means to see a viable passage toward gaining insight in explanation of motion. Only then will students really see the point of what they are going to do. This, after all, is what our problem-posing approach is all about.

Concluding remarks

We designed an introductory mechanics course for academically streamed students of about 16 years of age (Klaassen, 2006). The first half of the course is based on the 'in principle' outline sketched above. The second half concerns the evaluation of the theories of Kepler and Newton for planetary motion. This part is based on the claim that the epistemic virtues usually associated with good scientific theorizing (empirical adequacy, generality, ...) in the end are grounded in everyday plausibility judgments. So what can directively support students in the second half of the course, is their command of the appropriate epistemological resources needed to decide between alternative theories. In a modeling process of fitting and adjusting parameters, students are expected (1) to arrive at more or less adequate theories within both the Keplerian and the Newtonian scheme, (2) to weigh the relative merits of the two schemes in the light of the epistemic virtue of generality, and in the end (3) to make a validated choice for the Newtonian scheme.

A detailed evaluation shows that in earlier versions of our course we still fell short of reaching our aims (Westra, in press). The problems mainly concerned the first half of the course. One main problem was to make the basic structure 'come alive' in the sense indicated above, as familiar, somewhat elusive and yet providing a useful guideline. The other main problem concerned the problem of how to let it come 'alive' not just for individual students, but for a group of twenty to thirty students in a way that is manageable for a teacher.

Nevertheless, we still think that the 'in principle' outline can be made to work. We still believe that it is possible to tap students' causal knowledge and epistemic virtues in such a way that a sense of ownership is instilled in students concerning a viable way to tackle explanation of motion. We only need to improve our ways of tapping, so to say, and we think we are making progress in this respect (Emmett, Klaassen & Eijkelhof, 2006).

Let us close with a brief summary of our approach. We put a strong emphasis on *positively* exploiting students' existing knowledge, attitudes and abilities. In particular, we attempt to provide students with *content-based outlooks* on what they are going to learn and why. We try to do so by appropriately tapping some of their *core* knowledge, attitudes and abilities. We suggest that a similar approach be worthwhile for other scientific topics than mechanics too.

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Exploring Physics Teachers' Concepts of Simple DC Circuits

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Abstract

This research article depicts the result of a conceptual diagnostic test on simple DC Circuits undertaken by 26 physics teachers teaching at senior secondary level. Analysis shows that the teachers do have alternative conceptions related to simple DC circuits.

Qualitative analysis of their explanation justifying their answers reveals the cause of the alternative conception and the associated mental models. To bring in conceptual clarity a teaching strategy based on "Physics by Inquiry " has been developed which proved to be a successful one.

Introduction

Students mostly rely on teachers and their knowledge. A teacher with misconceptions can mislead the whole class and fail to bring in conceptual clarity. For improving the guality of the teaching-learning process in science, attention has to be focused on the training of teachers (in-service & preservice), and their level of performance in the classroom and laboratory. For teacher training alternative conceptions in a specific subject area are to be ascertained and training packages should be prepared, which will give them conceptual clarity and long term memory. In this research paper, electricity is chosen as the focus area. Many researches have been conducted to identify the misconception/alternative conceptions of students and teachers. Students' conception of electric current has been extensively studied at different levels of education (Duit et al., 1985; Shipstone et al. 1998; Fleer 1994; Borges and Gilbert, 1999; Shepardson & Moje, 1999). Students' concept of potential difference and current (Millar and Beh, 1993; Millar & King, 1993); electric circuits (Andre and Ding, 1991): electric diagrams (Johsua & Dupin, 1985); current and energy (Arnold and Millar, 1987) have been investigated. Comparatively fewer studies have been reported exploring teachers' understanding of the concept of electricity. However research done by Mc Dermott and Shaffer (1992), Webb, (1992) and Wiles & Wright, (1997) are worth noting. The present study evaluates the understanding of simple DC circuits by senior secondary physics teachers, which can not be ascertained directly without doing this descriptive research. Possible mental models associated with the alternative conceptions were identified. Finally the paper suggested an innovative teaching strategy for improving the learning situation of the teachers.

Conceptual frame work

Most of the research in the area under study are exploratory and descriptive. In some of the studies the researchers have used simple equipment like bulb, battery and connecting wires, and asked the students to connect the bulb and the battery so that the bulb glows. For individuals with previous knowledge of electricity, paper and pencil tests involving circuit diagrams of simple circuits, solution of problems followed by clinical interview and interactive sessions are generally preferred. For the present study a questionnaire containing diagrams of simple DC circuits have been used. Justifications for their answers to different questions were analyzed to know the alternative conceptions and the associated mental models of the sample. The mean scores for different questions have been calculated taking the correct answers into consideration which were used for different statistical analysis . One of the innovative teaching strategies based on "Physics by Inquire" was adopted to improve the knowledge related to simple DC circuits and its effectiveness was ascertained.

Research questions

1. Do the teachers have alternative conceptions related to simple DC circuits containing (i) a single cell and multiple bulbs (ii) multiple cells and multiple bulbs?

- 2. What are the associated mental models to the identified alternative conceptions?
- 3. Is Physics by Inquiry (PbI) an effective teaching strategy to bring in conceptual clarity related to simple DC circuits?

Methodology

Sample

The sample consisted of 32 postgraduate trained physics teachers teaching the subject at higher secondary level. Twenty six of them could complete the given questionnaire hence final sample consisted of 26 teachers. The following facts about the sample may be noted.

- These teachers work in central schools run by the *Kendriya Viidyalaya* Sangathan (KVS) an autonomous organisation under the ministry of Human Resource Development, Government of India. The major objective of KVS is to provide uniform pattern of quality school education to children drawn from different socio-economic background.
- The teachers were deputed to attend 21 days refresher course in physics to Regional Institute of Education, Bhubaneswar,a constitute unit of National Council of Educational Research and Training(NCERT) .NCERT is an apex resource organization set up by the government of India.The chief function is to provide academic and technical support for improvement of school education. The teachers belong to central schools located in twelve different states of India.
- All of them have completed at-least Master degree in physics and have undergone one year of professional teacher training course. All have more than ten years of teaching experience.

Tool

A diagnostic test was developed to measure the proficiency in the area of simple DC circuits. It was try –out and a revised questionnaire was prepared. A team of experts examined the content validity. Reliability of the diagnostic test (Set. I & II, Part A & Part B, Appendix I) was ascertained by using Test-retest method. Seventeen teachers were taken for the reliability test. The test was administered after a gap of fifteen days. One hour time was allowed for the test. Reliability coefficient was found to be 0.87. The questionnaire

contains two set of questions. Each question set contains three types of questions. The first part contains objective type questions carrying five marks. The second part contains a question related to comparison of brightness of bulbs in different circuits and carries two marks. The third part is the explanation part; it is based on one's reasoning. The second part is given in order to avoid guess work. The third part is not evaluated and is used to know the conception/ alternative conception and the associated mental model of the individuals. Part A and Part B (Set-I & Set-II) of this test was taken as the pretest.

Administration

The task is a pencil-on-paper task and one-hour time was allowed for the task. The teachers were not allowed to discuss during the test.

Scoring

Scoring was done for Part A & Part B of Set I and Set II. For Part A each correct option carries one mark and the Part B question carries two marks.

Analysis

The similar answers were grouped together. According to Gilbert and Watts (1983), "To generalize beyond the individual is to construct grouping of responses that are constructed as having similar intended meanings. The sample is divided into different categories and the % of response was calculated for both the set of questions and depicted in table1.

SL	CATEGORY	% OF RESP	ONSE
		SET-I	SET-II
1	Could answer all the questions correctly, grade the bulb correctly and correct explanation given.	23.07	19.23
2	Could answer all the questions correctly but could not grade the bulb. Explanation given supporting their reasoning.	23.07	15.38
3	Could answer all the questions correctly and grade the bulb correctly but no explanation given.	7.69	11.53
4	Could not answer all the questions correctly. Could not grade the bulb and gave incorrect explanation.	46.15	53.84

The average score obtained for Set I is 4.38 and for Set II is 3.30. t-test for non-independent sample was undertaken. t-value was calculated to be 6.544 which is greater than the t-value given for P=0.001. Thus the two scores are significantly different at < 0.001 level. The Pearson correlation coefficient 'r' for Set I & Set II was calculated to be -.0065. However the value is very small and one can safely take that the scores in Set I & Set II are not at all related

or the correlation is not significant. The transcripts of selected answers for the Set-I are depicted in Table-2.

.

Q. NO.	QUESTI	ON		ANSWER	EXPLANATION																						
1 a.	Bulb	Α	is	YES	Because `B' is in series with another bulb (correct)																						
	brighter bulb `B'		than	than	than	than	than	YES	Because `A' draws all current (incorrect, incomplete)																		
				YES	Because `A' in parallel & `B' in series (incorrect)																						
				YES	Because heat producedis more in `A' (correct but incomplete)																						
				YES	Because effective resistance of the second circuit is more (correct, incomplete)																						
YES Because current in the Fig.1 V/2R (Not correct as bulb is (Model : Universality of Ohm's					Because current in the Fig.1.a is V/R & 1.b. is V/2R (Not correct as bulb is not a ohmic resistor) (Model : Universality of Ohm's law)																						
	YES Because V is less, I is same in brightness is less than Fig.1.a. (inc																										
								YES	Because as connected in series bulbs B & C share the illumination in equal way (ambiguous)																		
												NO	Because bulb A, B, C all are in series with the battery hence will have the same illumination as for series circuit current flow remains the same (ambiguous) (Model : Constant current source model)														
				YES/NO	No justification																						
1b.	Bulb brighter bulb C	Bulb B brighter th bulb C	B is thar	is than	NO	Because `B' & `C' have the same power. (Calculated power by assigning potential difference and resistance for the bulbs) (Correct)																					
																											NO
				NO	Because they are in series (Incomplete)																						
				NO	Power in `B' & `C' is equal to V ² /R (Correct)																						
																NO	Because potential difference is same across both bulbs (Incomplete)										
				No	Potential difference is V/2 and current is I, so power is IV/2 for both the bulbs (correct)																						

Table-2 : Transcript of selected answers with associated explanation, Set-I

Q. NO.	QUESTION	ANSWER	EXPLANATION				
		NO	Because `B' & `C' have same current and same resistance, so I^2R is same for both the bulbs. (correct)				
		YES	Because of series connection (incomplet (Model : Current consumption model)				
		NO	Due to distribution of voltage in series connection (Incomplete)				
		NO	Voltage is divided so less bright (Incomplete)				
		YES/NO	No justification				
1 c.	Bulb D is brighter than bulb E	NO	`D' & `E' are parallel so will be of same brightness (correct, incomplete)				

		NO	Because power of both bulb are same (correct)	
1		NO	D' & E' are in parallel current is divided but potential is same (Correct, Incomplete)	
		NO	Current in each bulb is same so will glow with same brightness (incomplete)	
		YES	D' is nearer to the cell (Model: Current consumption model)	
		YES/NO	No justification	
1 d.	Bulb F is brighter than bulb G	YES	`F' is parallel and if the power is V^2/R , power of G and H will be $V^2/4R$ (Correct)	
		NO	Because `F' & `G' bulbs are parallel with each other (ambiguous)	
1		YES	If power for `F' is $I^2R/4$, power for G is $I^2R/8$ (incorrect)	
		YES	Effective resistance is the cause (incomplete)	
		YES	If current in bulb `F' is V/R current in bulb `G' is V/2R. (Model : Universality of Ohm's law) (Incomplete incorrect)	
		YES	Because `G' is in series with `H' and `G' is parallel to the cell (incomplete)	
		NO	`F', `G', `H' will equally share the voltage as all are connected parallel to the cell (incomplete)	

Q. NO.	QUESTION	ANSWER	EXPLANATION
1 e.	Bulb G is brighter than bulb H	NO	Power of both bulbs are same i.e. V ² /4R (correct)
		YES	G' is nearer to the positive terminal hence will glow brighter than H' (Model : current consumption model) (Incorrect)
		NO	Current is V/R in both (ambiguous)
		NO	G' & H' have same current and resistance (incomplete)
		NO	`F', `G', `H' will glow equally bright because they equally share the potential (ambiguous)

Analysis reveals that the teachers have a tendency to treat bulbs as Ohmic conductors or linear-resistances. The same tendency has been conformed for the college going students (Metioni <u>et.al</u> 1996). Applicability of ohm's law, its limits and validity is at stake. Analysis of explanations as depicted in Table. 2 reveals that the teachers have the following alternative conceptions related to the question Set-I.

- Bulb nearer to the positive terminal of the cell is brighter than the other bulbs in the circuit. This alternative conception is due to "current consumption model" (Karrqvist, 1985; Borges & Gilbert, 1999). Current flows from positive to negative plate of the cell. Hence nearer the bulb to the positive terminal more is the current.
- Bulb is treated as a linear resistor. This alternative conception is due to "universality of ohm's law" (Metioui *et al*, 1996). According to this model, for ohmic resistance, resistance remains same irrespective of the value of V or I, which is also true for a bulb.

 Current from a cell does not depend on the number of bulbs in the circuit. This alternative conception is due to "Constant current source model" (Cohen *et al*, 1983).

Table-3 depicts the transcripts of selected answers with associated explanation for Question set - II.

Q. NO.	QUESTION	ANSWER	EXPLANATION
2 a.	Brightness of the bulb A and B will be same in all the diagrams.	YES	In Fig. 2C, the bulbs will not glow. In Fig. 2a, 2b, and 2d the cells are in series and hence emf adds up where as in Fig. 2.c the emfs oppose and net emf is zero (Correct)
		YES	Because of Kirchoff's second law. In any closed mesh of an electrical circuit, the algebraic sum of the products of the currents and resistances of the various branches of the mesh is equal to the total EMF of the mesh, (used the correct law but could not analyze)
		NO	A ₁ , A ₂ & A ₄ are nearer to the positive terminal of the cell hence will glow brighter than B's (incorrect) (current consumption model)
2 b.	Brightness of the bulb B_1 and B_2 are not equal	NO	There is no difference between Fig.2.a and 2.b. Hence they will glow with same brightness (correct, incomplete)
		NO	Cells are in series, bulbs are also in series (correct)
		YES	Brightness of B_1 is greater than Brightness of B_2 , as the cells are nearer to each other in Fig.2a (incorrect)
2 c.	Brightness of the bulb B_2 and B_4 are not equal	NO	Brightness of B_2 and B_4 are equal. Cells are in series and emf adds up (correct)
		YES	Due to change in position of the cell (incorrect, incomplete)
		YES	B ₄ is nearer to the positive terminal of the battery (ambiguous) (Model : current consumption model)
		YES/NO	No justification

Table-3 Transcript of selected answers with associated explanation, Set-II

Q.	QUESTION	ANSWER	EXPLANATION
NO.			

2 d.	Bulb B_4 is brighter that bulb B_3	IN YES	B_3 will not glow at all where as B_1 , B_2 , B_4 will glow with equal brightness. Because in Fig.2.c, same polarity of the cells are connected (Correct)
		YES	For bulb B_3 potential difference is zero hence it will not glow, where as B_4 will glow with same brightness as A_4 . (Correct)
		NO	Both bulbs are connected in series. (Ambiguous)
2 e.	Bulb B ₄ is brighter tha bulb B in Set I	IN YES	Two batteries in series so energy available is more (correct)
		NO	Same current passes through bulb B and B ₄ (incorrect, incomplete)
		NO	Both will glow with same brightness as both are in series with another bulb. (incorrect) (Constant current source model)
		YES/NO	No Justification

Analysis of answers related to Fig. 2a and 2b reveals that the teachers have a perception that changing the place of cells in the circuit affects the brightness of the bulbs. With this feed back one can see the loop hole in traditional teaching strategies. Hence to improve the teaching learning process some of the research based teaching strategies should be included in the pre-service and in-service teacher training programs. The identified mental model associated with alternative conceptions of the sample for question set II, is mainly due to current consumption model, universality of ohm's law and constant current source model.

Training module

Learning science usually involves fundamental restructuring of existing knowledge to bring in conceptual change. For conceptual change, it is important to understand the existing knowledge/ preconception, the learner carry to the classroom. It helps the facilitator to understand the thinking process of the learner and how they misinterpret when the facilitator/ instructor teach and they read. The teacher/ facilitator can help the student to acquire/ construct more productive models provided the teachers are equipped with knowledge of different mental models and teaching sequences (Borges et al. 1999). Constructivism approach of teaching-learning process helps in building mental models and is the root of long-term memory and recall. This research work reveals that though the teachers have content knowledge i.e. the theories of electricity but the functionality is missing. For constructing knowledge many instructional modules have been developed based on cognitive models like cognitive conflict and bridging. However development of physics by inquiry (PbI) is a very strong research based method, which can be used to construct the related concepts by bringing in conceptual change. This process helps in discovering rather than memorising and teaching is by questioning rather than by telling. Inquiry based physics learning is nothing but active learning laboratories in which along with traditional laboratory work interactive approach has been associated . During these periods students work in pairs with simple equipment and are guided to

reason through physical examples with apparatus and carefully prepared worksheets. Trained facilitators help students to find their own path to understand by guiding them with carefully chosen question. PbI provide the students with opportunity for

- Thinking
- · Reasoning and
- Making sense of what they observe during the experiment in a coherent and consistent fashion.

Lillian Mc Dermott has reported the success of PbI for pre-service elementary school teachers at the University of Cyprus for simple DC circuits. For the present purpose a module was prepared by directly following the relevant PbI given in the book entitled "Physics by Inquiry" an introduction to physics and the physical sciences, Volume-II published by John Wiley & Sons. INC, 1995 written by Lillian C. Mc Dermott with Peter S. Shaffer and Mark L. Rosenquist and Physics Education Group, University of Washington. This module is prepared for understanding the circuits with single cell and multiple bulbs. However similar module can be prepared for multiple cells and multiple bulbs. One practical session of two hours duration had been utilized for the intervention, by dividing the sample into thirteen groups.

The students were instructed to go through the module (appendix III) and answer the questions which were followed by a group discussion.

Post Test

A post test was conducted. A gap of fifteen days time was in between the pre-test and post-test. The reliability of the post-test was ascertained to be 0.83 Its content validity was established by a group of expert. The learners were allowed to check their results with the staff members after depositing the post-test problem. The questionnaire used for post test has been given in appendix-II. It contains Part A & Part B similar to Set I & Set II used for pretest given in appendix-I. The marking pattern is the same as the pretest. The mean score of post-test is 6.42. t-test was used to determine whether two means i.e. the mean of pretest and post test are significantly different? Here ttest for non-independent samples was used. t-value was calculated to be 5.645 for 25df. Thus one can safely conclude that after the intervention there is significant improvement. Thus the PbI teaching strategy proved to be very effective.

Conclusions

- Physics teachers with highest formal education and long teaching experience possess alternative conceptions related to simple DC circuits.
- Mental models like current consumption model, constant currentsource model and universal applicability of ohm's law are prevalent with the teachers.
- o Scores of Set-I and Set-II are not correlated.
- Mean score of Set-I and Set-II are significantly different. This indicates low performance in Set-II compared to Set-I.
- Physics by Inquiry is proved to be an effective teaching strategy for the Indian physics teachers for teaching DC circuits.

Suggestions

- In Physics teacher training programme (pre-service/ in-service) innovative teaching strategy like PbI should be included.
- Teaching module based on innovative teaching practices should be developed for all concepts in physics and included in teacher training programme.

For appendix – I,II,III contact dr.mad.ma@gmail.com

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Appendix-I

TEST ON SIMPLE DC CIRCUITS

Name:

School/College:

Gender:

Date:

Instructions

In the following circuits it is assumed that

a. the cells are ideal cells i.e the internal resistances are zero.

b. the connecting wires have zero resistance.

c. all the cells are identical

Set-I

Study the following four circuit diagrams and answer the questions



Part (A)

Choose the correct option ($\sqrt{}$)

1 a	Bulb A is brighter than bulb B	:	YES/NO
1 b	Bulb B is brighter than Bulb C	:	YES/NO
1 c	Bulb D is brighter than Bulb E	:	YES/NO
1 d	Bulb F is brighter than Bulb G	:	YES/NO
1 e	Bulb G is brighter than Bulb H	:	YES/NO

Part (B)

Grade the bulbs A,B,C H in order of decreasing brightness.

Part (C)

Explain your answers for questions given in part-A.

Set-II

Study the following circuit diagrams and answer the given questions.



Part (A)

Choose the correct option ($\sqrt{}$)

2 a.	Brightness of bulb A and B will be same in all the diagrams.	:	YES/NO
2 b.	Brightness of bulb B1 & B2 are not equal	:	YES/NO
2 c.	Brightness of bulb B ₂ & B ₄ are not equal	:	YES/NO
2 d.	Bulb B ₄ is brighter than bulb B ₃	:	YES/NO
2 e.	Bulb B ₄ is brighter than bulb B in set-I	:	YES/NO

Part (B)

Grade the bulbs B₁, B₂, B₃, B₄ in order of decreasing brightness.

Part (C)

Explain your answers, given for the questions in part-A

Appendix-II

TEST ON SIMPLE DC CIRCUITS

Name:

School/College:

Gender:

Date:

Instructions

In the following circuits it is assumed that

- a. the cells are ideal cells i.e the internal resistances are zero.
- b. the connecting wires have zero resistance.

c. all the cells are identical

Study the following circuit diagram and answer the questions.



Part A

Choose the correct option ($\sqrt{}$)

1 a.	Bulb A is brighter than bulb C	:	YES/NO
1 b	Bulb B is brighter than bulb C	:	YES/NO
1 c	Bulb D & E glow with equal brightness	:	YES/NO
1 d	Bulb D is brighter than bulb F	:	YES/NO
1 e	If bulb C is removed brightness of bulb A will increase	:	YES/NO

Part (B)

Grade the bulbs A, B, C, D, E, F in order of decreasing brightness.

Appendix III

The module

Experiment No-I Connect a battery with a single bulb using wires so that it will glow. Use a key to increase the longevity of the battery.

--

Exercise I-a Is a complete circuit is necessary for a bulb to glow? Does this observation suggest that the glow in an electric circuit is one way or round trip? Can you explain how a bulb glows?



- **Experiment No-II** Fig. 1 Connect another bulb in series with the first bulb. Close the switch
- **Exercise II-a** Compare the brightness of the bulbs with the brightness of an identical bulb in a single bulb circuit.



Exercise II-b Compare the brightness of the bulbs in a series circuit with each other. What can you conclude from this observation about the amount of current through each bulb ?

Exercise II c On the basis of your observations and reasoning you used to answer the above questions, respond to the following question-

Is current "used up" in the first bulb or the same amount of the current flow through both bulbs?

Explain your reasoning to a staff member/ facilitator.

- **Experiment No-III** Add a third bulb in series.
- **Exercise III b** Explain your observation with reasoning to a staff member.



Experiment No-IV

Connect a bulb in parallel to the bulb in Fig I.

Exercise No-IV a

Compare the brightness of each bulb with the brightness of the bulb in Fig. I



Exercise No-IV b Compare the brightness of the two bulbs in the two bulb parallel circuit with each other. What can you conclude from observation about the amount of current through the bulb?

Exercise No-IV c On the basis of your observations and reasoning you used to answer the above question respond to the following question.

- Compare the brightness of the bulbs when the two bulbs are both on the same side of the battery and when they are on different sides.
- Compare the brightness when each bulb has separate leads to the battery and when the terminals of the bulbs are connected together and then connected to the battery.
- **Exercise No-IV d** Describe the flow around the entire circuit for the two bulb parallel circuit. What do your observations of bulb brightness suggest about the way the current through the battery divides and recombines at the junctions where circuit splits into the two parallel branches?
- **Exercise No-IV e** What can you infer about the relative amounts of current through the battery in a single-bulb circuit and in a circuit in which two identical bulbs are connected in parallel across the battery?
- **Exercise No-IV f** Does the amount of current through a battery appear to remain constant or to depend on the number of bulbs in a circuit and how they are connected?

The learner after using the above module will realize that

- Brightness of the bulbs in Fig. I and Fig. IV are the same indicating that current passing through them is the same. In Fig. IV current from the battery is divided equally between the two bulbs. The flow of current through the battery for the circuit as given in Fig. IV is more than circuit given in Fig. I.
- Adding bulbs to a circuit may increase or decrease the total resistance. It depends on how you add them. If you add them in parallel, you give the current more pathways, so the total resistance is less. If you add them in series the resistance is more and current through the bulbs will be less and the brightness decreases.

Using Pictures as Active Models in a Thinking Journey mode of Teaching Physical Concepts

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Abstract

The paper reflects on the argument on the effectiveness of using pictures in teaching. The way is shown to use pictures as a model in teaching the concept of the Earth's rotation. The advantages of such a use are ascribed to the mediation by a teacher provided while using pictures in a special mode of teaching – Thinking Journey (TJ). It is explained why such use may improve the results of teaching the day-night cycle in the middle school and surpass the success of using regular material model of a globe. The activity uses real pictures of the Earth and Mars. Questions regarding estimation of time in a particular location on the planet encourage students to mentally manipulate the pictures thus essentially improving their knowledge of the subject. The applied approach of multiple perspectives helps students to construct scientific understanding of the day-night cycle as an invariant of their experiences.

Introduction

There is an argument on the effectiveness of using pictures in teaching. Schnotz and Bannert (2003) addressed detrimental effects of such use. In this article we elaborate the advantages of using pictures of astronomical objects as models for teaching about the rotation of the Earth. The advantages of such a use are ascribed to the mediation provided within a special mode of teaching – Thinking Journey (TJ) (Schur et al. 2002; Schur and Galili, 2006). The mode employs pictures of the considered phenomenon made from different perspectives of the observer and in a variety of natural environments. This way the concept to be taught emerges through comparison between various contexts as their invariant core. The active manipulation of pictures by the learner of physics makes them an effective model and stimulates the development of students' ability to imaging different views on the object, a precondition of successful learning.

Regular teaching of day-night cycle and Earth's rotation with material models

Using an illuminated from a side Earth's globe (or any spherical object), as a model for daynight cycle and Earth's rotation is common. One can represent this teaching approach mentioning the following points:

- 1. The *teacher* illuminates the globe from aside using a strong source of light. He/she brings the attention of the students to the illuminated areas on the globe, explains and visualizes the day-night exchange phenomenon.
- 2. The *students* listen to the teacher and observe the demonstration. It is supposed that observing the demonstration and listening to explanations present a sufficient condition for a new knowledge to be constructed.
- **3.** It is common that the phenomenon of day-night circle is presented from one particular perspective: as seen by an imaginary observer located far enough from the Earth. The day-night cycle is seen as a process of exchange of area status: illuminated for day and non-illuminated for night.
- **4.** Understanding of the phenomenon of day-night cycle and Earth's rotation is considered to be reached through an *individual* interpretation of the provided explanation.
- 5. The learning takes place in considering a highly artificial model and in fact is based on the developed ability of imagination and abstract reasoning.
- 6. The approximate nature of the material model.
 - **a.** When the day-night cycle is learned students can easily see the "night" part of the globe, although it is not illuminated directly. In reality, however, the night half of the Earth is normally not seen at all by a remote observer who sees only the illuminated part of the Earth (a phase shape).

b. By all means, the globe, and especially a simple ball often used to represent the Earth, does not look as the real Earth. Besides the mentioned phase shape, instead of a full sphere, the model never represents the true appearance of the Earth for the neglected dominance of atmosphere (clouds normally cover half or more of the familiar outline of the continents).

In fact, such an instruction is highly abstract, despite of its apparently concrete nature, it looks totally disconnected from the conception of a rotated planet to many of the young learners. Novice learners of physics are not ready for the assimilation of scientific knowledge from a transfer of abstract information. Indicatively, being asked to draw the Earth from outside, say from the Moon, students normally present our planet as a full sphere with clearly seen continents (no clouds, no phases), whereas in real observations it is often rather difficult even to identify a continent, not speaking about specific countries. The low effectiveness of teaching the topic of Earth and day-night cycle is well known to teachers and researchers (e.g. Baxter 1989).

The alternative approach within TJ

We advocate here an alternative way of teaching, Thinking Journey, in which the scientific knowledge is mediated to students making an active use of *real* images representing the *real* Earth and containing the necessary representation of the considered concept, also in a variety of perspectives (Schur and Galili 2006). The idea is to take a picture and make it a stage of an imaginary journey of the students to the depicted environment. While performing a conversation on the subject the teacher initiates and encourages considering the depicted phenomenon from the provided perspective and in the specific environment. Teacher's questions guide students to manipulate with the presented picture as if it presents a material model. The understanding of the goal concept is constructed from a series of interactions. We exemplify it in the following.

First interaction



Teaching Earth's rotation around its axis starts with the class exposure of a photograph of the Earth taken from a spaceship far enough to see the "whole" planet (Fig. 1). Our country, Israel, well known in its outline to our students, can be identified in this picture. The learning interaction begins with the teacher asking: "What was the time in Israel at the time this photograph was made?"

In fact, the teacher invites the students to make several mental actions: a. Students have to identify Israel in the picture; b. They have to appreciate the meaning of the line separating the illuminated and non-illuminated areas of the Earth (the terminator); c. To evaluate the time instant students start hypothetical thinking regarding the

changing the situation in time, "Does the situation change?", "In what direction does the Earth turn?" d. To estimate more precisely the hour in Israel, the students should apply proportional reasoning: how far is Israel from the terminator?

After the estimation of the time is made, students are asked to imagine themselves there, in Israel, at that moment and describe the day-night changes as they would take place from that moment. Students are asked to make a report of their hypothetical experience. The normally provided descriptions include light changes usually taking place during the day-night cycle: dawn, noon, twilight time, sunset, night. While describing their experience students perform an imaginary journey, drawing on the life experience they accumulated. Slowly, the revolution of the Earth, the succession of its entering and leaving the darkness becomes a natural element of the story and thus the relevant students' knowledge is established.

Second interaction



At the next step the teacher repeats the process, asking the same question about the time in Israel while showing pictures of the Earth on which Israel might be seen in different perspectives or not seen at all (Fig. 2).

The picture in Fig. 2 was made from a satellite and has America continents in its center, Israel does not appear. In such a situation, in order to estimate the time in Israel the students have to imagine its location on the globe relatively to the shown geographical place and subsequently reveal that the absence of Israel in the picture of the illuminated Earth implies Israel being at night. Proportional thinking might help in determining the specific hour. The time difference between America and Israel (about 7-10 hours), known or

provided to the students, is realized in this context in its operational meaning. The discovery of the time hour variation and the relationship of the day hours between different locations on the Earth (the knowledge of time at some place determines the hour at another) also contribute to the learning of day-night cycle being conceptually related to this concept.

Third interaction



In this interaction the whole context is changed. Day-night cycle is relevant to any planet and therefore the concept might and should be learned in this broader aspect. The next interaction employs the picture made by a spaceship approaching Mars (Fig. 3).

The picture shows the globe of Mars partially illuminated. Observing the picture, one naturally sees its salient feature on the illuminated surface of the planet: a huge volcano (Olympus Mons). The teacher asks: "What time is now at this point (the volcano)?" While presenting the question teacher mentions the nature of the object (answering natural curiosity) and two important facts about Mars, its rotation period (about 24 hours) and the direction of its spinning in the perspective of the considered picture.

Going through a similar dialogue with the students regarding Mars strengthens the knowledge of day-night cycle by its application to a different context. The dialogue may expand and touch on another particular feature of this unique picture: light spot in the dark part of Mars. Not far from the terminator line the top of the high mounting area (Southern Pole) is seen being illuminated by the Sun while its vicinity apparently remains in the darkness of night (approaching the morning). Understanding of this feature further strengthens students' concept of day while learning about day-night cycle.

Cognitive skills involved

Our approach is sensitive to the need of the learner to master some cognitive skills essential for the success in learning physics. Within the considered mode of learning, TJ, teacher is aware of and helps to promote the following major cognitive functions of the students:

- 1. *Relationship between the viewer's location and the kind of appearance of the observed phenomenon.* The learner knows precisely where he/she is located and tries to imagine the special view determined by this location.
- 2. *Mental manipulations with the picture.* Seeking the answer to the particular question the learner needs to mentally manipulate the picture considering the changes expected in the future and reconstructed from the past. This activity implies manipulation with the picture as with a material model.
- 3. *Construction of a mental model of day-night cycle.* Going through a series of tutorials the students perform analysis of several situations and by identifying the similar and the different in them they make an inference regarding the concepts of day-night cycle and rotating Earth.

Summary

Our approach to teaching about day-night cycle within TJ interactions uses pictures as interactive models implying a significant change to *the role of the teacher* who guides a dialogue in the context designed to fit the goal concept and chosen pictures. The dialogue is not only a stimulating and interesting activity, but provides the teacher with an opportunity of mediation the scientific contents and cognitive tools of science to the learners.

Students find themselves being involved participators, engaged in the process of knowledge construction. This role causes their many questions of various types, not only about "what", but also about "how does it happen?" and "which way we know that it is so?".

The TJ based approach deliberately employs multiple views on the considered subject of the Earth's rotation which causes concept construction as an invariant from several contexts.

Using real pictures of Earth or Mars as models reduces the level of abstraction associated with using material artificial models in the class. Day-night cycle becomes an observed reality of any planet. Such a use of pictures for thinking journey is effective and introduces a new enjoyable way of teaching and learning physics.

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Teacher Candidates' Understanding of Momentum and Impulse

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Abstract

This study was conducted in a large faculty of education with the participation of teacher candidates from different majors and years. The literature review showed that there is not a significant number of research studies conducted on teacher candidates' learning of impulse and momentum. Hence, the purpose of this research study was two fold: first, to determine how the teacher candidates defined the concepts of momentum and impulse; second, to determine the level of successful application of these concepts to problems. Data were collected through written responses to openended questions and four multiple-choice questions that can be solved by using momentum and impulse concepts. Participants were required to give extended responses for all questions. Thus, the raw data were mostly qualitative in nature. They were scored by three researchers first independently and then together. This researcher triangulation ensured reliability of data analysis and the subsequent interpretation of findings. The findings reveal that freshman students, by and large, were not familiar with these concepts, and that during their four-year study the participants majoring in teaching physics developed a substantial gain in defining these concepts. However, the results suggest that there is still room for further development in teaching and learning of these concepts at this level. It was also found that students experienced difficulties in applying the impulse-momentum theorem. The major difficulties were: not drawing limits of the system examined, disregarding internal/external forces, and ignoring that momentum is a vector quantity.

Introduction

Research on science education has gained an impulse since 70's and 80's (Duit, 1993). Especially researchers from Northern America, Europe, and Australia have investigated what students from different age groups and backgrounds think about natural processes (Halloun and Hestenes, 1985; Driver, et.al., 1994; Treagust, Duit, and Fraser, 1996); how science education effects their thinking (McDermott, 1991; Hewson and Hewson, 1983); their learning processes (Niedderer, Goldberg, and Duit, 1992; Fischer, 1993; Niedderer, 1997; Roth, 1998); evaluation and the nature of science subjects from the perspective of teaching and learning. In the light of these research studies new and innovative teaching strategies have been developed.

As the analysis done by Duit shows even by early 90's in about 40 journals the number of papers published on students' conceptions in physics, chemistry, and biology is around 2800. About half of these were published after 1977 mostly of which were about physics subjects (66%). It was also found that mechanics as a research subject area topped all other physics subjects (about one fourth of all papers) and also the percentages of papers belonging to the chemistry and biology categories. This shows how intensely the mechanics subject area was studied. All these research studies on student conceptions and the findings obtained have contributed to the development of teaching techniques and the design of school science curricula (e.g. Camp and Clement, 1994; and Wells, Hestenes and Swackhamer, 1995).

In years researchers also studied how momentum and impulse are understood and learned by students. Camp and Clement gave a list of student misconceptions about collisions. Some of the interesting ones in that list are as follows: During a collision the body with greater speed, mass, or rigidity applies a greater force on the other; on the other hand, if a body is slowing down it applies less force. These authors did not only list the common misconception but also developed and provided a teaching unit with lesson plans based on students' alternative conceptions by utilizing bridging analogies. Raven's 1965 doctoral dissertation entitled "An investigation into the concept of momentum in primary school children" is one of the first in this line of research (Raven, 1967-1968). In this study the purpose was to determine the order of presentation of concepts in order to meaningfully comprehend momentum. Results showed that pupils from kindergarten through grade 3 (ages 5-8) had from the beginning an intuitive understanding of momentum without understanding how the elements that make up the concept of momentum individually contribute to the whole. At college level it was found that many students' had a lot of difficulty in direct applications of impulse-momentum and the work-energy theorems (Lawson and McDermott, 1987). Authors argue that rote memorization is not sufficient by itself and stress that applications of these concepts to real world situations require deeper understandings. Moreover, they emphasize that those essential aspects of the concepts that cannot easily be visualized can be overlooked if just told orally by the instructor or described verbally in textbooks.

More recently researchers investigated different aspects of teaching and learning of these concepts by using various theoretical frameworks. In this frame students conceptual change processes during learning collisions in relation to conservation laws (Grimellini-Tomasini, Pecori-Balandi, Pacca and Villani, 1993); modeling forces in collisions and Newton's third law (action-reaction forces) (Lattery, unpublished manuscript); computer aided learning of energy, momentum and conservation laws in laboratories (George, Broadstock and Vásquez Abaz, 2000); understanding the conceptof momentum and its mathematical expression (Wessel, 1997); a hierarchic developmental modeling of students' understanding of momentum (Graham and Berry, 1996). In addition, conceptual tests of force and motion (i.e. Hestenes, Wells, and Swackhamer, 1992; Hestenes and Wells, 1992; Thornton and Sokoloff, 1998; Mazur, 1997) that were developed for measuring and diagnosing student misconceptions also include related items.

In order to model hierarchicly the steps taken while learning momentum and impulse the 20-item "momentum hierarcy survey" was deleoped (Graham and Berry). In an administration of this survey to a large group of students (N=549) of ages 17-18 it was found that grossly they can be grouped into four categories: those who are confused with the concepts (ignoring mass and largely depending on speed when thinking about momentum); those who can understand the basic ideas, recognize relavant situations, and make calculations without knowing the relationships between momentum and impulse and the law of conservation of momentum (still have difficulty in perceiving momentum as a vector quantity); those who are progressed in the hierarchy further and can understand momntum as a vector quantity and apply impulse-momentum theorem and the law of conservation of momentum in one dimentional problems; lastly the forth group who completely comprehend the concept of momentum (together with the nature of momentum can also show in one way or another that they understand the situations in two dimentions).

Hasweh (1988) divides research studies methologically into three groups: descriptive studies, explanatory studies, and those testing conceptual change. In the first group of studies students' preconceptions need to be determined and described. Methodologically, no suggestions, conclusions or inferences are made in this group of studies as to how learning takes place or how an educational model supports conceptual change since no findings are obtained towards how conceptual change occurs and only diagnosis formed. Hence, descriptive studies do not have direct educational implications. It can only be established which methods and techniques are more beneficial within what kind of strategies, after conducting explanatory studies and studies test them.

By using the interviews about instances technique Jones (1983), Watts (1983), and Osborn (1985) have investigated students alternative and pre-conceptions. In this technique students are presented certain situations, preferably from daily life, containing a problem and their views and ideas are extracted by open ended questions. In this way responses are analyzed to see if they form a pattern. In such studies qualitative analysis of participant responses is needed. It is often tricky if only one researcher evaluates the responses since there exists a threat of subjective scoring. One of the important tools is, thus, utilizing researcher triangulation in order to eliminate interpretation mistakes stemming from subjective evaluation of individual scorers. Researcher triangulation has great importance for maintaining objectivity in forming categories based on participant responses (Denzin, 1970). When done correctly and carefully it provides an opportunity to minimize mistakes and portray what is in the data more accurately.

By conducting intwerviews or obtaining responses to open ended questions there is an opportunity to uncover interviwees ides as they exist within their minds and more authentically since participants are not forced to choose among a limited set of predetermined options. Although qualitative data analysis is time consuming and messy, it is very useful in determining the richness in students ideas. In such studies it is essential to determine especially what exists in the field about a chosen issue about which only little or non is known (such as teacher candidates' ideas about momentum) rather than to observe how a certain case will come about in a certain field of observation (Strauss and Corbin, 1998, pp. 10-14).

Rationale and Purpose

When the relevant literature is reviewed and examined it is seen that i) the number of research studies specifically conducted on momentum and impulse is limited as compared to other physics subjects; and ii) there exists no research study on teacher candidates' understanding of these concepts (defining, describing, and conceptualizing). Therefore, new studies are needed that will detect and diagnose difficulties in teaching and learning of these concepts. In addition, it is also needed to investigate how and to what degree teacher candidates learn and understand these concepts at the beginning and throughout their university education.

The purpose of this study was to investigate teacher candidates' background and current state of knowledge of the concepts of momentum and impulse and how they apply what they know in different situations. The aim was to contribute to the existing body of literature by obtaining data and subsequent rigorous analysis. The conclusions of this study are expected to reveal teacher candidates' conceptual difficulties together with other relevant learning difficulties regarding momentum and impulse.

Data Collection

The data in this study were collected during the first two weeks of fall semester in several sessions since the participants constituted of different majors and years. A total of 192 teacher candidates participated in the study. The majors, years, and the respective numbers of participants are given in table 1.

Major and Year		Number of students (<i>N</i>)	Percentage	
High School Physics Teaching – I	(HSPT-I)	39		20%
High School Physics Teaching – II	(HSPT-II)	32		17%
High School Physics Teaching – III	(HSPT-III)	22		11%
High School Physics Teaching – IV	(HSPT-IV)	42		22%
Middle School Science Teaching – I	(MSST-I)	17		9%
Middle School Maths Teaching – II	(MSMT-II)	40		21%

Table 1. The majors, years, and the respective numbers of participants.

It should be noted that MSST and HSPT majors take introductory mechanics courses in fall semester of their freshman year, MSMT majors take it in their sophomore years. That is the reason for including MSMT-II group in the sample.

The participants were given a two-part questionnaire (see box 1). The first part contained several questions aiming to measure conceptual understanding regarding momentum and impulse. And the second part contained questions requiring providing descriptions. Participants were asked to provide extended responses to all of the questions.

Box 1. The qustionnaire. Figures were provided for qustions 2 and 3 (not shown here).

1. Consider that you have a ball in your hand. Is momentum conserved when you release it and after hitting the ground if it returns back to where it was released? Explain why you think so.

2. Choose one of the options and explain your answer.

As shown in figure consider that you are standing on a cart with ignorable friction with the surface. You are throwing balls onto a panel fixed firmly to the cart. If the balls bounce directly back as shown will the cart move? (Mazur, 1997, p. 134).

- a) Yes, moves toward right.
- b) Yes, moves toward left.
- c) No, stands still.

3. Two objects with mass m and 2m are at rest on a frictionless surface. If these two objects are pushed for 3 seconds with equal forces, how many times more will be the momentum of the lighter object as compared to the heavier one? (Mazur, 1997, p. 129).

a) 4 times b) 2 times c) equal d) half e) a quarter

4. Three astronauts Joe, Bob, and Tom who weigh equal on earth. While they are at rest in outer space Joe pushes Bob towards Tom with a velocity **v** and Tom catches Bob. Describe the motions of these three astronauts at these instances by also describing the direction and magnitude of their velocities (Hewitt, Suchocki & Hewitt, 1999, p.74).

5. What is momentum?

6. What kind of a quantity is momentum? Why?

7. What is the unit of momentum?

8. What is impulse?

Data Analysis and Findings

Response sheets were scored according to a rubric by each of the researchers individually and then together in order to ensure reliability of interpretations and avoid subjective evaluation mistakes. Indeed, it was seen during data analysis that this way of researcher triangulation considerably reduced such mistakes.

According to the rubric one of three codes were assigned to each response:

- [0] : denotes scientifically unacceptable or no response cases,
- [1]: denotes scientifically complete and acceptable responses,

[2] : denotes responses that contain acceptable or nearly acceptable expressions.

Analysis of responses to the first question:

Two sorts of answers are considered in category [1]:

A) When the ball's momentum considered alone it will not be conserved, since momentum is a vector quantity. Even though the magnitude of momentums just before and after collision they are in opposite directions. When the ball is considered alone it under the influence of an external force (earth's gravity). Momentum is not conserved under the influence of an external force.

B) When the earth and ball system is considered together momentum is conserved. This is like the case of colliding two objects. Since the earth's mass is too large as compared to the ball's mass it will not, practically, gain an acceleration. There is no external force for the earth-ball system and the total momentum is conserved.

It is noteworthy that only two responses out of 192 are in category [1]. Seventeen responses are considered in category [2], and the remaining bulk of the responses, 173, are in category [0].

Analysis of responses to the second question:
A response is considered as [1] if it states and explains that the cart will move towards left and shows that impulse is equal to the change in colliding balls' momentum. If the correct choice is signed but an explanation is not provided it is included in category [2]. Analysis of responses are given in Table 2. It is seen that participants are in real confusion when they are required to respond to a problem that can also be answered intuitively.

					Cate	egories	
Major and Year	Number of codes			Number of responses			Percentages in categories
	[1]	[2]	[0]	[1]	[2]	[0]	6 6
HSPT-I	4	11	8	7	17	15	[1] 17.9% [2] 43.6% [0] 38.5%
HSPT-II	4	4	8	16	5	11	[1] 50% [2] 50% [0] 34.4%
HSPT-III	2	1	12	6	1	15	[1]
HSPT-IV	3	3	13	15	4	23	[1] 35.7% [2] № 9.5% [0] 54.8%
MSST-I	1	2	6	3	3	11	[1] 17.7% [2] 17.7% [0] %64.6
MSMT-II	2	7	14	3	15	22	[1] □ 2.5% [2] 37.5% [0] 55%
TOTAL	16	28	61	50	45	97	

Table 2. The number of codes and students in each category for question 2.

Analysis of responses to the third question:

A response is considered as [1] if it states and explains that according to the impulsemomentum theorem the changes in momentum of the two masses will be equal or that according to Newton's second law mass and acceleration are inversely proportional if forces are equal for two different masses. Since momentum is the product of mass and velocity both bodies will have equal change of momentum. Analysis of responses are given in Table 3. It is seen that physics teaching majors are gaining more accurate understandings as they progress through the years.

					egories		
Major and Year	Number of codes			Number of responses			Percentages in categories
	[1]	[2]	[0]	[1]	[2]	[0]	
HSPT-I	2	4	11	13	5	21	[1] 33.4% [2] ₩ 12.8% [0] 53.8%
HSPT-II	3	2	6	24	6	2	[1] 75% [2] 18.8% [0] ■ 6.2%
HSPT-III	2	0	6	15	0	7	[1] 68.2% [2] - 0.0% [0] 31.8%
HSPT-IV	3	2	3	36	3	3	[1] ■ 85.8% [2] ⊠ 7.1% [0] ■ 7.1%
MSST-I	1	2	7	2	4	11	[1] □ 11.8% [2] 23.5% [0] □ 64.7%
MSMT-II	2	4	11	13	5	21	[1] 0.0 % [2] 30.0% [0] 70.0%
TOTAL	13	14	44	103	23	65	

Tablo 3. The number of codes and students in each category for question 3.

Analysis of responses to the fouth question:

In this question there is no external force acting on any of the bodies involved. Also there is no friction since the astronauts are not on a surface. So, it needs some abstract thinking. However, the question can be solved easily by applying the law of conservation of momentum. In the first part Bob should move with velocity \mathbf{v} towards Tom and Joe should move backwards with the same speed.



In the second part Tom, while at rest, catches Bob. Afterwards, they move together (with the same speed). Their speed should therefore be half the speed of Bob.



Most participants responded to this question (85%). One fourth of all students correctly answered this question. One third of the responses were counted in category [2]. These contained correct responses to either part of the question. It is noted that overwhelming majority of participants in this group correctly answered the first part of the question. Considering that students are more familiar with collision problems, this finding represents a perplexing situation.

As a result, more than 40% of the responses were counted in category [0] 15% of which were no response cases. It was also noted that too many codes emerged for this question. (see table 4). Therefore only the most frequent ones are presented in table 5.

Major and Year	Number of codes			Number of responses			Percentages in categories	
	[1]	[2]	[0]	[1]	[2]	[0]		
HSPT-I	1	6	19	2	10	27	[1] □ 5.1% [2] 25.6% [0] 69.2%	
HSPT-II	1	7	4	13	11	8	[1] 40.6% [2] 34.4% [0] 25%	
HSPT-III	1	4	5	10	5	7	[1] 45.5% [2] 22.7% [0] 31.8%	
HSPT-IV	1	10	4	19	15	8	[1] 45.2% [2] 35.7% [0] 19%	
MSST-I	1	2	10	2	5	10	[1] 11.8% [2] 29.4% [0] 58.8%	
MSMT-II	1	10	11	2	18	20	[1] □ 5% [2] ↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓	
TOTAL	6	39	53	48	64	80		

Tablo 4. The number of codes and students in each category for question 4.

Tablo 5. The most frequently seen response patterns for question 4.

G (Number	D (1st]	Part	2nd Part	
Category	of responses	Percentages	Joe	Bob	Bob	Tom
[2]	21	10.9 %	←V	$V \rightarrow$	-	$V \rightarrow$
[2]	9	4.7 %	←V	$V \rightarrow$	$V \rightarrow$	$V \rightarrow$
[2]	67	34.9 %	←V	$V \rightarrow$	-	$2V \rightarrow$
[0]	5	2.6 %	\leftarrow	\rightarrow	-	\rightarrow
[0]	4	2.0 %	0	$V \rightarrow$	-	0
[0]	3	1.6 %	←V/2	$V/2 \rightarrow$	-	$V/2 \rightarrow$
Total	109	55.7 %				

Analysis of responses to the fifth question:

Besides responding to problem situations it is also important to be able to formally define concepts as they are accepted in the scientifically. When participants' responses about definition of momentum are analyzed and coded it is seen that only one third of them were in category [1]. However, it is also seen that physics teaching majors achieved considerable gain in defining this concept as years passed (30.8%, 31.2%, 59.1%, and 71.4% respectively for years 1-4).

Analysis of responses to the sixth question:

Defining momentum as a vector quantity is essential in understanding the concept fully. Therefore, participants' responses are important in relation to their definitions of the concept. It is seen that participants who had not yet taken introductory physics courses yet, are in great difficulty in giving appropriate and acceptable responses (15.4%, 0%, and 7.5% respectively for HSPT-I, MSST-I, MSMT-II). But in subsequent years HSPT majors had better results (59.4%, 31.8%, and 64.3% respectively for HSPT-II, HSPT-IV). It is noted that there is a jump right after taking the introductory physics course).

Analysis of responses to the seventh question:

Units of physical quantities are important to recognize while learning concepts, but students often fail to do so. The data shows that HSPT majors attained a better level of success in their responses to this question as compared to the fifth question (see table 6). Again it is seen that upper level participants are far better in responding to this question than lower levels.

					Categories				
Major and Year	Number of codes			Number of responses			Percentages in categories		
	[1]	[2]	[0]	[1]	[2]	[0]			
HSPT-I	3	3	10	13	5	21	[1] → %33,3 [2] ₩ %12,8 [0] → %53,9		
HSPT-II	4	3	4	24	3	5	[1] ^{%75} [2] [№] %9,4 [0] [™] %15,6		
HSPT-III	6	2	1	19	2	1	[1] [2] [0] ■ %4,7 [0] ■ %4,7		
HSPT-IV	8	1	2	39	1	2	[1] %92,9 [2] ₿ %2,4 [0] ■ %4,8		
MSST-I	1	0	7	1	0	16	$ \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \frac{\%5,9}{12} = \frac{\%0}{10} $		
MSMT-II	2	1	8	3	1	36	[1] □ %7,5 [2] 8 %2,5 [0] %90		
TOTAL	24	10	32	99	12	81			

Tablo 6. The number of codes and students in each category for question 7.

Analysis of responses to the eighth question:

Impulse is a very closely related concept to momentum. Lastly, participants definitions of impulse were probed by directly asking to define the concept. Here a similar pattern like in the sixth question is observed in participants' responses to defining impulse. Also, it is noted that participants who had not yet taken the course virtually were not aware of the concept. This time much so for the HSPT majors also (only 7.7% of this group of participants' responses were counted in category [1]).

Some participants tended to define the concept as "momentum=impulse" rather than "**change** in momentum=impulse". This tendency was also observed in a small group in responses to defining momentum. This finding shows that some students had heard about these concepts and their relation to each other but they were not accurately remembering and/or explaining them.

Results and Discussion

The purpose of this study was to investigate teacher candidates' background and current state of knowledge about momentum and impulse and how they apply what they know in different problem situations. The data obtained in this study revealed eye opening results in order to determine the current state of affairs regarding the above stated research problem. The first and far most important finding is that participants' initial knowledge state is not adequate. They virtually do not know even the basics such as definitions and have considerable difficulty in applying their existing knowledge to problems. One example of this was seen when participants' responses to questions 1 and 6 are evaluated together. Although, about half of the participants knew that momentum is a vector quantity they failed to apply this piece of knowledge when responding to question 1 and the majority stated that (56%) the mass and speed of the ball is the same while falling down and climbing up and therefore the momentum is conserved.

Another important finding, when considered upper level HSPT majors also participated in this study, is that almost all of the students do not distinguish the role and importance of internal/external forces in collisions and conservation of momentum. Therefore, emphasis must be given and attention must be paid during instruction, if students come to an understanding of this sort as a result of learning the concepts. Another study (Grimellini-Tomasini, Pecori-Balandi, Pacca, and Villani, 1993) also presented similar findings with regards to isolation of the system in hand from the surrounding and considering momentum as a vector quantity in dealing with conservation of momentum. Current study also revealed such difficulties students' have and confirmed agreement with the above mentioned study. One implication that can be drawn from this study is that in teaching conservation of momentum the role and importance of internal/external forces in collisions should be sufficiently stressed and examples should be given for both cases where momentum is conserved or not conserved.

It is also seen as a result of this study that although HSPT majors showed a considerable positive gain in learning as years progressed there still a lot to do in defining the concepts of momentum and impulse and solving related problem situations.

When it is considered that in this study the participants were actually teacher candidates, it should also be mentioned that in this open-ended extensive response survey participants had difficulty in explaining and expressing their own views and ideas. The importance of this finding becomes obvious since teachers are not educated for themselves only and training and educating future teachers also demand fluent individuals in expressing themselves.

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From diagnosis to treatment: Diagnosing understandings about force and motion and providing analogies for stimulating meaningful learning and conceptual change

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Abstract

Student misconceptions in science and particularly about force and motion have been studied over the years. These studies provide a wealth of knowledge for researchers and educators. The purpose of this study was to develop a diagnostic test that can easily reveal student misconceptions about force and motion. The Force and Motion Diagnostic Test was developed over the years and addresses Newton's first and second laws of motion. Teacher candidates were administered the test and consecutively their misconceptions were identified. The test consists of 20 true / false questions about a situation described both verbally and by providing a graph in the question. The situation involves an object on which a net force is applied. However, during the first half of the whole time the force diminishes linearly and becomes zero and then it increases again linearly in the opposite direction. The true/false questions, besides the correct scenario, also model typical student misconception like "there is no motion unless there is a force," "speed is proportional to applied force," and "objects always move in the direction the force is applied." On top of revealing student misconceptions the provided situation in the question also assesses how participants understand the concept of acceleration. The concept of acceleration is the key to understanding Newtonian mechanics. Without comprehending this concept appropriately no meaningful learning is likely to occur. Therefore, two daily life analogies for acceleration outside physics are provided for in class discussions that can foster desired understandings about acceleration: population growth rate, and inflation of prices.

Introduction

Students' ideas about force and motion has been investigated in numerous studies at different levels and settings. Indeed, it has been the most intensely studied area in science education research (Duit, 1993). In time, standard comprehensive tests have been developed (e.g. Hestenes, Wells & Swackhamer, 1992; Hestenes & Wells, 1992; and Thornton & Sokoloff, 1998) again to reveal students' ideas about what effects forces bring about.

Driver, Squires, Rushworth, and Wood-Robinson, (1994, p. 149) highlighted students' alternative ideas about force and motion as follows:

- \oplus if there is motion, then a force must be acting;
- \oplus if there is no motion, then there is no force acting;
- \oplus without motion one can not talk about force;
- \oplus when a body moves, there must be a force in the direction of motion;
- \oplus a moving body will stop when its force is exhausted;
- \oplus there exists a force in moving bodies that maintain motion;
- Φ motion is proportional to acting force;
- ♦ a constant velocity (in 1-D) is brought about by a constant force.

It is seen that these and other alternative conceptions are very persistent to change and present a learning difficulty for learners at all levels (see for example Tasar, 2001). Therefore diagnosing students' alternative conceptions and presenting a helpful treatment for them is extremely important for developing instruction and fostering meaningful learning.

Purpose

This research study is based on the common naïve idea that "force and velocity are directly and linearly related." It is extremely important to determine whether students are subscribed to this idea or hold scientific conceptions expressed by Newton's laws.

Method

For this purpose a 20 item true/false questionnaire called "The Force & Motion Diagnostic Test" (FMDT) has been developed. Here a case of diminishing net force is presented with a graph where the net force increases in the second half (see also questions 14-21 in Tools for Scientific Thinking: Force & Motion Conceptual Evaluation in Thornton & Sokoloff, 1998). It is observed that students are not familiar with such kind of changing net force in time and consequently undergo difficulty in understanding and responding to such cases. It is also seen that such varying force questions has a great potential to reveal student understandings of Newton's Laws. The force described in the questionnaire can be obtained on an object as seen in figure 1.

Here a toy car, on a sufficiently large table with frictionless surface, is connected to two buckets filled with sand. Initially bucket B is filled with twice the amount of sand in bucket A. The hole at the bottom of bucket B lets sand to leak uniformly. This system initially has a uniformly decreasing net force towards right. The net force on the toy car becomes zero, when the amount of sand in bucket B equals the amount of sand in bucket A. Afterwards, the increasing net force is towards left since the amount of sand in bucket B continues to decrease until there is non left.





THE FORCE & MOTION DIAGNOSTIC TEST (FMDT)

 F_1 A force is applied on an object initially at rest. The figure shows the change in <u>net</u> force in time on the object (t₀ denotes the beginning of application of force, t₁, t₂, t₃ and t₄ denotes equal time intervals). The direction of force₀ is reversed at t₂. Which of the judgments below are TRUE or FALSE about the motion of the object during t₀ – t₄ time interval?



- 1. At t_2 where force becomes zero velocity will be <u>zero</u>, too.
- 2. At t₀ and t₄ velocity will have its **<u>maximum</u>** value.
- 3. At t₂ velocity will have its **maximum** value.
- 4. At t₂ the object's direction of movement will be <u>reversed</u>.
- 5. The object's direction of movement will <u>not</u> change between $t_0 t_4$.

-F

- 6. At t₂ the object will **<u>stop</u>** momentarily.
- 7. At t_4 the object will be at the point <u>where</u> it started its motion.
- 8. At t_4 the object will be at the <u>farthest</u> point with respect to where it began its motion.
- 9. At t_1 and t_3 the object will be at the same point but moving in opposite directions.
- 10. At t₀ the velocity will reach its maximum, then will gradually decrease and afterwards will linearly increase in the <u>same</u> direction.
- 11. At t₀ the velocity will reach its maximum, then will gradually decrease and afterwards will linearly increase in the **opposite** direction.
- 12. The velocity of the object will be <u>zero</u> at t_0 , t_2 , and t_4 ; whereas at t_1 and t_3 it will have the <u>maximum</u> values.
- 13. The object will start its motion with zero velocity, and it will steadily speed up; and then in the second half it will steadily slow down until it stops.
- 14. The object's velocity will <u>increase</u> at a decreasing rate, and then will <u>decrease</u> at an increasing rate.
- 15. The object's velocity will <u>increase</u> at an increasing rate, and then will <u>decrease</u> at a decreasing rate.
- 16. The object's velocity will <u>increase</u> at a decreasing rate, and then will <u>decrease</u> at an decreasing rate.
- 17. The object's velocity will <u>decrease</u> at an increasing rate, and then motion will be <u>reversed</u> and velocity will <u>increase</u> at an increasing rate.
- 18. The object has a **constant** acceleration throughout its motion.
- 19. The object has a <u>decreasing</u> acceleration in the first half and an <u>increasing</u> acceleration in the second half of its motion.
- 20. The object has an **increasing** acceleration in the first half and a **decreasing** acceleration in the second half of its motion.

The test was administered in mid 2006 spring semester to a total of 80 middle grades science teacher candidates in two groups. There were 39 participants in one group and 41 in the other. Participants were in their junior years. Science education majors take introductory physics courses in the first year. So, this test was administered 2 years after taking the physics courses.

The 20 questions can be divided into 5 groups (or themes): magnitude of velocity, direction of velocity, position of the object, the form of velocity vs. time graph, and acceleration. Since it is observed in in-class discussions previously that students' propose a large number of forms for the velocity-time graph for such a motion eight most common ones were included as statements in the questionnaire.

Findings

As seen in table 1 only 10% of the participants correctly predicted the results in all four themes. Other response patterns are also given in table 1.

Table 1. Response patterns (\times non-appropriate, and \checkmark appropriate response combinations for each theme).

Theme	Magnitude of velocity	Direction of velocity	Position of the object	The form of velocity vs time graph	Acceleration		Number of Responses		Percentages
Related questions	1, 2, 3	4, 5, 6	7, 8, 9	10,11,12,13, 14,15,16, 17	18, 19, 20	Group A	Group B	Total	
Correct response patterns	FFT	FTF	FTF	FFFFTFFF	FTF	<i>N</i> =39	<i>N</i> =41	<i>N</i> =80	
	×	×	×	×	×	8	8	16	20.00
	×	×	×	×	✓	20	19	39	48.75
·	✓	×	×	×	×	0	1	1	1.25
S	✓	×	×	×	✓	0	2	2	2.50
ior	×	~	✓	×	✓	0	2	2	2.50
nat	×	~	\checkmark	✓ (13-14)	×	0	2	2	2.50
idn	~	>	×	×	\checkmark	1	0	1	1.25
col	✓	\checkmark	✓	×	×	1	0	1	1.25
Ise	✓	×	✓	✓	✓	0	1	1	1.25
por	✓	×	✓	✓ (13-14)	✓	1	0	1	1.25
est	✓	 ✓ 	✓	×	✓	0	1	1	1.25
ц. Ц. Ц.	√	√	\checkmark	✓	×	1	1	2	2.50
-	√	\checkmark	√	✓ (13-14)	×	2	1	3	3.75
	✓	✓	✓	✓	✓	3	0	3	3.75
	 ✓ 	\checkmark	\checkmark	✓ (13-14)	\checkmark	2	3	5	6.25

Some participants regarded items 13 and 14 similar or complementary to each other. This was also seen in a previous administration of the test (Tasar, 2002). Hence, if a participant signed item 13 together with item 14 as true then the fourth theme for such cases is considered appropriate.

When first three themes are considered only 18.75 % (N=15) of the participants did not show any misconceptions. It should also be noted that most participants (68.75 %, N=55) correctly predicted the pattern of acceleration resulting from such a changing force in time.

When responses were evaluated in terms of if they show misconceptions it is seen that more than two thirds of the participants hold misconception regarding force's effect on motion. About a quarter (22.50%) of the participants showed perfect misconception pattern in their responses to the first three themes.

Theme	Magnitude of velocity	Direction of velocity	Position of the object	Number of Responses			
Related questions	1, 2, 3	4, 5, 6	7, 8, 9	Group A	Group B	Total	Percentages
Response pattern showing the misconception	TTF	TFT	TFT	N=39	<i>N</i> =41	<i>N</i> =80	
	✓	✓	✓	10	8	18	22.50
	✓	✓	×	2	1	3	3.75
	×	✓	✓	9	8	17	21.25
	✓	×	✓	0	3	3	3.75
	×	✓	×	2	1	3	3.75
	×	×	✓	2	8	10	12.50
			TOTAL	25 31.25%	29 36.25%	54 67.50%	

 Table 2. Number of respondents showing complete or partial misconceptions regarding first three of the themes.

Results and Implications

It is seen that most science teacher candidates cannot respond appropriately to the questions and consequently it is inferred that most of them still hold misconceptions about force and motion. It is noteworthy that although about half of them (48.75%) can figure out the relationship between force and acceleration, they cannot comment correctly on force's effect on velocity (speed in 1-D) and resulting displacement. This can be associated with rote memorization of concepts. The results show that only 10% can correctly answer all questions. Most definitely this is not a desired level of achievement for teacher candidates. By and large, there exists a huge gap between their understandings of the concepts and the scientifically accepted ones.

It would also be interesting to see the results when the questions in this survey are put into a multiple choice form and statements in the fourth theme are presented as graphs. Different force variations can also be utilized for this purpose.

In order to remedy this gap between student understandings and scientific concepts two suggestions are presented below. These are analogies for force (acceleration) and velocity and can be used during in-class discussions to stimulate meaningful understandings. These analogies, when remembered and referred to in the future, can serve as powerful tools to overcome conceptual difficulties and foster conceptual change.

Since the relationship of force and velocity are neither direct nor linear instructors, by presenting appropriate analogies preferably already known by their learners, can help overcoming conceptual difficulties. Force is related to the change in velocity by Newton's second law. If there is a change in velocity then there must be a net force applied or vice versa. If there is no net force applied then the law of inertia applies (no change in velocity).

Similarly, if inflation in prices is reduced that does not mean that the prices will also be reduced. It simply means that prices will increase in a decreasing rate (contrary to the layman's interpretation that prices will fall). If inflation rate is steady, then it means that prices are going up at a constant rate. If inflation rate is going up in time, it means that prices are increasing at an increasing rate.

In the same way, an analogy can be made between rate of change of population and acceleration. If the population increase rate is reduced then the population increases at a lower rate, but never decreases. If the population increase rate is constant then the population increases steadily.

It is suggested here that by discussing these analogies a more meaningful understanding of the relationship between force (acceleration) and motion can be achieved. This is seen as the key since the findings here suggest that although students understand the relationship between force and acceleration they cannot predict the features of resulting motion.

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University students' models of electricity and their relation with historical representation of Physics

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Abstract

Educational research overwhelmingly shows that in formal instruction, students use knowledge (ideas, strategies, criteria and representations referred to entities, process, interactions and related concepts) that may be different from present accepted Physics knowledge.

Some authors suggest that there is certain similarity between alternative schemes of students, and explanations developed by precursors of present Physics. In this paper this kind of similarity is explored for university students' representations about electricity.

We present research results concerning the following models used by students:

- A "kinetic model" for electric energy, which associates electric energy exclusively to the movement of charge circulating in a circuit

- An "isolationist model" for electric energy, which assigns to electric energy an absolute status and treats it as an intrinsic property of each element.

- A "substantial model" for electric energy and field, which assigns to electric energy and field the properties of substances.

- A "sequential model" for electric field, which considers electric field as an entity propagating from the source and suffering progressive alterations while encountering obstacles along its path.

We hope these results may contribute to deepen the comprehension of students' unscientific representations, in order to suggest criteria to improve teaching practice.

Introduction and presentation of the problem

The present paper is part of a research, which proposes to analyse university students' comprehension, in the framework of Classic Physics, about the notions of energy and electric field. The results were obtained with engineering students from the second year at National University of Tucumán, Argentina. The instruction received by the students corresponded to habitual characteristics in basic university cycles and consisted in theoretical classes, practical and theoretical sessions of problem resolution and laboratory experiences.

The theoretical framework of the investigation integrates convergent contributions from different fields of knowledge, like cognitive psychology, history and science epistemology. Nowadays, there is an increasing consensus about a constructive orientation of learning (Resnik 1983; Driver 1986), which, among other aspects, admits the using of alternative ideas, strategies and representations by the students. This group of non-scientific knowledge doesn't seem significantly modified by habitual teaching based in a verbal transmission model of knowledge. Overcoming models of teaching and learning, consider it is essential to bear in mind these aspects during the process of formal instruction (Salinas, Gil, Cudmani 1995).

Furthermore, some authors state the hypothesis that in some fields there is a certain similarity between alternative student's schemes and historical scientific models (Bachelard 1972; Piaget 1972 y 1975).

We explored possible similarities between historical and university student's electricity models. We identified the following models used by students.

Students' models

- A "kinetic model" for electric energy, which incorrectly associates electric energy to the movement of the charge circulating in a circuit.

We detected answers like "electric energy is the flow of electrons" or "going through resistance, the electrons brake and lose electric energy". Statements like these show that many students conceive incorrectly the electric energy like a kinetic and non-potential kind (Velazco y Salinas, 2002). On the other hand these could manifest confusions between electric current and energy. According to students' ideas a resistance produce a decrease of the current (and of the electric energy, non differentiated from the other) when it passes through the resistor, caused by a diminution of the speed of the carriers.

We could point out that the potential electric energy of the electrons decreases while they pass through resistance, but this variation is due to change of electric potential throughout the conductor and not a decrease of carriers' speed.

Other researches show, in mechanics area too, that many students associate the idea of energy only to body movement (Solomon 1983).

From historical perspective, in XVII century there was a development of three great thought lines connected to Descartes, Newton and Leibniz (Tarsitani and Vicentini 1991). In an attempt to explain a world apparently in constant change, there arise hypothesis of conservation of the total quantity of matter and of magnitudes linked to its movement.

Particularly, according to the leibnizian tradition, matter possesses a sort of energy, or "force", which Leibniz called "vis viva" that in movement bodies is measured like mv^2 and in physical processes is conserved. For Leibniz, the matter is continuous and its parts are distorted, admitting elastics collisions preserving the vis viva or present force and the vis mortua, or latent force. While cartesian tradition admits the conservation of the force (interpreted as the quantity of movement and as a scalar magnitude) in the universe, Leibniz postulates the conservation of the vis viva.

The strong association of "vis viva" (or energy) to bodies in movement keeps a certain similitude with the ideas expressed by the students.

- An "isolationist model" for electric energy, which treats electric energy as a property of each element, without relating it to the notion of system or to the interaction between its parts.

We have detected, for example, that many students consider that a capacitor "will always store the same amount of energy"; some of them incorrectly say, "the maximum energy that a capacitor could store is independent of the tension supplied by the source" (Velazco and Salinas, 2002). These students seem to interpret the capacitor as a container, which can always contain the same maximum quantity of something like a liquid in an independent way of the rest of the elements which compose a circuit. As we know, this kind of answer is scientifically incorrect because potential electric energy of a capacitor represents the external work done by the source to charge the capacitor and it depends on the amount of charge deposited.

Other educational research carried out in areas like mechanics and thermal phenomena_also show that students tend to interpret the phenomena in terms of properties which are associated only to the object of interest, in detriment of possible interactions between that object and the system of which it would be part (Pacca and Henrique 2004).

On the other hand, even though the "vis mortua" introduced by Leibniz could be considered the germ of the present concept of potential energy, it is important to point out that this last concept differs considerable from the previous one. To Leibniz, the vis viva and the vis mortua would be intrinsic properties of each matter portion and their values in each instant would be independent of the presence of the other system components. This way to conceive phenomena has got a certain resemblance with the students' ideas. Let us bear in mind, that from a present scientific perspective, the potential energy of a system depends on its global state. It is a representative property of the work that has been done to take the system to its actual state from a given state of reference.

- A "substantial model" for electric energy and field, which assigns to electric energy and field the properties of substances.

Educational research has showed that many students materialize abstract entities which are hardly comprehended, among them, electric energy and field.

In the case of electric energy we found answers compatible with underlying models that conceive energy as some kind of fluid that has an objective existence. As we have mentioned, many pupils consider "*the energy stored by a given capacitor will always be the same*". This kind of answer shows that they could use a mechanical model to the capacitor charge process and that, as a result, they would treat energy as a substance (Velazco and Salinas, 2002).

Duit (1987) and Solomon (1985) have also detected, in other areas of physics, materialist conceptions about energy: many students conceive energy from a material point of view, as some kind of substance which is used for the benefit of men.

In relation to the electric field concept, we have detected expressions or graphic representations from students that seem to express an electric field model as a material entity that emanates from the source and is affected by obstacles in its way. So, for example, when being questioned about the electric field of a punctual charge in a point placed behind an infinite wooden plate, some students consider that the wood "allows the field to pass through". For other students "the charge field can not pass through the plate". Therefore, the students treat the plate as a physical limit that obstructs (or not) the passing of a substance through it (Velazco and Salinas, 2001).

Historical analysis shows that in science were used material models to explain different types of phenomena, even though afterwards, they would become epistemological obstacles (Bachelard, 1972) that should be overcome by the scientific community. So, for instance, scientist from XVIII century such as Black and Watt considered heat as a weightless substance, not possible to create and impossible to destroy (called caloric) that passed from a body to another. The caloric theory constituted a conceptual base for calorimetric experiences where global quantity of heat conservation was manifested. The caloric notion was subsequently overcome by dynamic theory of heat, which associated it to microscopic movements of matter and it was supported by experiments like the ones made by Rumford in 1798, that showed the equivalence between heat and work (Taton, 1975).

In addition, the explanations based in material models also contributed to the origin of the idea of field: many electricians of XVIII century considered that the electric fluid was expanded around charged bodies producing an "*electric atmosphere*" or "*effluvium*" (Garcia Doncel 1987). Material models showed persistence in historical evolution of field concept: Faraday introduced the notion of "force field", substance to which he conferred direction and sense and which would impregnate the whole universe. Maxwell proposed a newtonian theory for the field and considered that it could be interpreted in terms of movements, deformations and tensions of the "ether", substance that would fill all space and would be subordinated to Newton's laws. Lorentz renounced to all ether mobility but he preserved the ether in his theory as a material support for the field.

It was Einstein who realized about the nonessential character of ether and rejected it, eliminating in that way, in his world vision the material conception of field (Berkson, 1985).

- A "sequential model" for electric field, which considers electric field as an entity that is propagated from the source and it is altered progressively when finding obstacles interposed in its way.

We detected that students treat the field as a mechanical perturbation which can be transmitted step by step: some students state the idea that the field of a punctual charge surrounded by a conductor shell is expanded from the source and acts in a point in virtue of modifications produced in the medium interposed between the source and the point. Thus, the field of the punctual charge would only be in the region limited by the conductor, would act on the conductor inducing charges and these charges would, in turn, be the only field sources in the later region to that conductor (Velazco and Salinas).

Similarly, in coincidence with what was reported by other researchers, we have detected that when the material obstacle is an isolating, some students suppose that a charge will also act in an indirect way, by the dielectric polarization (Viennot and Rainson, 1992).

From a historical point of view, we can quote Faraday who is considered the creator of the field theory. Faraday used sequential models to explain electric and magnetic interactions. We can mention, for instance, a note written by Faraday in 1832:

"...When a magnet acts on another one or on a piece of iron placed to certain distance, the influential cause (that for the moment I will call magnetism) advances gradually from the magnetic bodies and requires some time for its transmission, time that will surely be verified as appreciable. I think I have reasons to suppose that electric induction has likewise a place in a progressive similar interval" (Faraday dated by Berkson, 1985).

Showing certain analogy with the explanation given by students, Faraday describes a charge or magnet action on a point through a sequential explanation.

Final comments

Without establishing a strict parallelism, the analysis we have made shows the existence of some punctual similarities between the most primitive historical models about energy and field and some representations used by students:

The association of energy concept predominantly to bodies' movement

- The character conferred to energy, treated like an intrinsic property of matter and non related to system and interaction notions

- The tendency to use material models to explain natural behaviours

• The use of sequential models.

Several educational researches show that students manifest tendencies of common sense to make conceptions ruled by perception and intuition. There are evidences, like the ones showed in this work, that students use, in a similar way to the historical predecessors of science, mechanic visions to interpret physical phenomena, among them, the electric ones. It is possible that these epistemological obstacles become really persistent, just like it happened in the historical construction of energy and field models.

Indeed, the history of science shows that there should elapse many years, so that the classic notions of energy and electric fields acquire the characteristics which define them today. Scientific community had to overcome enormous difficulties during the historical construction process of those ideas. This suggests that in the teaching process these concepts should not be treated in a quick and superficially way and help us to understand and not to underestimate our students' difficulties.

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Learning Quantum Mechanics

Modelling electronic transitions in the hydrogen atom

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Abstract

We interpret the square of the so-called probability density as a measure of the density of a substance or material, the electronium. Correspondingly, the probability curent density becomes the current density of the electronnium.

We show pictures of calculated electronium density distributions for the various states of the hydrogen atom, as well as animations of electronic transitions. The electronium model explains several properties or phenomena by means of arguments from classical physics:

1. The shape of atoms and molecules.

2. The orbital angular momentum results from the circulating mass flow.

3. The magnetic moment results from the circulating charge flow.

4. Since for stationary states the current density is constant in time, these states are non-radiative.

5. When two eigenstates are superposed, the density and the current density oscillate. In such a state the atom radiates. The selection rules can be deduced with purely electrodynamic arguments.

In physics, we use models for various purposes. What does this word mean: a model? We want to describe or to understand a physical system X. We now choose an object M from our everday experience in such a way, that it behaves similarly to X. M must not behave like X in every respect. It just has to show certain similarities. We now operate with M instead of X, or in other words: We operate with a model of X. Using the model we draw conclusions and we translate our conlusions to the original system X. If all this is done skillfully and if we are lucky, we obtain correct statements about X. It goes without saying, that this procedure works only if we know how to operate with our model. That means – it was already said – that the model must be an object of our immediate experience.

Consider from this point of view that model of the atom that nowaday is used almost exclusively: The atom consists of a small and heavy nucleus and a big and light electronic cloud. The electrons themselves are small in comparison with the entire atom. Sometimes it is said that they are pointlike. The position of a particular electron is not defined. One can only give a distribution of the probability for finding an electron in a given volume element. Moreover, it is said, that the electron moves around the nucleus, but it is also said, that the concept of trajectory ceases to be meaningful. Now, there is a problem with this model. The problem is not, that the model does not fit into reality. Any model reflects the real or original system only partially. The problem is rather that it is not clear at all how to work with the model. The reason is that the model just mentioned does not represent an object of our everyday experience. We never have seen a body that does not have a well-defined position. We never have seen an object that moves but does not have a trajectory. With such a strange object, one does not know at all which operations are permitted. In order to operate with it, we need to know the complete theory. But that would mean, that we don't need the model anymore.

We now discuss an alternative model. Suppose ψ is a solution of the Schrödinger

equation. We define two quantities ρ and j:

$$\rho = \psi^* \psi$$
$$j = \frac{\hbar}{2mi} \left(\psi^* \nabla \psi - \psi \nabla \psi^* \right)$$

Using these definitions and the Schrödinger equation, with a small calculus we obtain:

$$\frac{\partial \rho}{\partial t} + \operatorname{div} \boldsymbol{j} = 0,$$

an equation that has the form of a continuity equation. This suggests to interprete the quantity ρ as a measure of the density of a substance or a fluid, that is distributed around the nucleus. j would then be a measure of the corresponding current density. Since in the following we often have to refer to this substance, we give it a name: electronium. The electronium model reproduces various phenomena correctly. We only need to know the properties of a classical fluid that carries mass and electric charge. In the following we shall discuss various examples.

The shape of the atom

The quantum-mechanical calculus, provides us with pictures of $\psi^* \psi$. Figure 1 shows the state with n = 4, l = 3 and m = 1 of the hydrogen atom. The external surface corresponds to 10 % of the maximum density. When using the electronium model such pictures are interpreted as reflecting the shape of the atom in the corresponding state. The traditional interpretation, according to which such functions respresent probability densities, would forbid such a view.





Angular momentum and magnetic moment

Figure 2 corresponds to the state with n = 3, l = 2 and m = 1. The picture on the left shows the density distribution and that on the right shows the current density. In the picture at the left red means the highest density and blue corresponds to zero. In the picture at the right red means the the flow is oriented out of and blue into the drawing plane. The flow lines are circles around the vertical central axis.



Fig. 2. Density (left) and current density (right) for the state n = 3, l = 2, m = 1. In this state the atom has angular momentum and a magnetic moment.

One of Bohr's postulates tells us that there are circular electronic orbits in which the electron does not emit radiation and it is declared ("postulated") that in this case

electrodynamics isn't valid anymore. With the electronium model we have not to abrogate electrodynamics. On the contrary, electrodynamics tells us that there is no emission of radiation: In an eigenstate of the energy the charge density as well es the current density are constant in time. Therefore, the resulting fields are stationary, i.e. non-radiative. The electronium model is in agreement with electrodynamics.

There is more that is explained by the electronium model. We consider states with $m \neq 0$. (Only in these states the electronium flows around the nucleus.) Since there is a mass current and an electric current associated with the circular flow of the electronium we expect that the electronium has angular momentum and that it has a magnetic moment. The values of both these quantities can be calculated from the current distribution and both results are in agreement with the values obtained by solving the eigenvalue equation.

Dipole transitions

The electronium model shows its power above all in the description of electronic transitions. An electronic transition from one stationary state to another can be described in semi-classical approximation by superposing the wave functions of the initial and the final state. The density of such a state is easily calculated and one obtains an expression of the following form:

$$\rho(\mathbf{r},t) = C_0(\mathbf{r}) + C_1(\mathbf{r})\cos(\omega t).$$

Now the density is time-dependent. The charge oscillates with the frequency $\omega = (E_A - E_B)/\hbar$, where E_A and E_B are the energy eigenvalues of the initial and final state, respectively. Classical electrodynamics tells us, that the atom must emit a sine wave, in agreement with what we know from quantum mechanics.

Videos showing various transitions can be downloaded from

www.physikdidaktik.uni-karlsruhe.de.

Let us consider first a transistion from the state 2p to 1s, that is a transition with $\Delta l = 1$. One clearly sees an oscillation, i.e. an up and down of the electric charge, similar to an oscillating dipole. From electrodynamics we know that such an object must radiate. Because the oscillation has a dipolar character the radiation is strong. The atom loses its energy quickly and therefore the transition from the excited state to the ground state is fast.

Quadrupol transitions

We consider a transition with $\Delta l = 2$: (n = 4, l = 3, m = 1) to (n = 2, l = 1, m = 0). The movement of the charge distribution has clearly a quadrupole character. From electro-dynamics we know that such an object radiates only weakly. Therefore, the transition is slow. Customarily one says that it is forbidden.

Circular polarization of the emitted radiation

Our last example is a transition from (n = 2, l = 1, m = 1) to (n = 1, l = 0, m = 0). The charge distribution displays a circular movement. Classical electrodynamics tells us, that we get the emission of a wave that is circularly polarized.

Conclusion

Although all these things are known since the beginning of quantum mechanics, there never prevailed a proper name for what we propose to call electronium. In his quantum mechanics textbook Döring [1] calls it ,,electron matter" (Elektronenmaterie). He also deplores that not more advantage is taken of the great explanatory power of this model.

[1] W. Döring: Atomphysik und Quantenmechanik II. Die allgemeinen Gesetze, Walter de Gruyter, Berlin 1976, p. 20

Learning Quantum Mechanics through Experience

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Abstract

In teaching quantum mechanics to freshmen at the University of Amsterdam, a setup is being developed that relates theory to observation. Assignments have been designed following the Van Hiele level scheme. In short, this scheme states that students learn via three successive levels: the visual, descriptive, and theoretical level. In the observed educational practice, the first two levels are often left out, causing confusion and misunderstanding amongst students.

As a starting point the idea of energy levels was discussed in an assignment on the spectrum of hydrogen. Students were able to reason at the first two Van Hiele levels, but a transition to the theoretical level was difficult. This approach can be extended to more difficult concepts, such as the wave function.

Introduction

At the University of Amsterdam, quantum mechanics is taught in the first year, second semester. Two courses take part in a research on the learning of quantum mechanics: Quantum Physics (QP) for physics students and Quantum Chemistry (QC) for chemistry students. As a first step in the research, learning difficulties have been identified (Koopman, 2005). We get the impression that students often learn tricks, instead of understanding what they are doing: students are able to do most calculations, but often do not understand the physical meaning. Furthermore, several difficulties were observed that also appear in other literature on this subject (Fischler & Lichtfeldt, 1992; Styer, 1996; Johnston, Crawford *et al.*, 1998; Steinberg *et al.*, 1999, Müller & Wiesner, 2002). For instance, many students seem to hold on to a classical interpretation of the wave function. They think the wave function represents the trajectory of the particle. In addition to this, chemistry students have great difficulty with the abstract nature of the theory, and their mathematical skills are problematic (Koopman *et al.*, 2006).

We believe that students will have a better understanding of theoretical concepts, when these concepts are related to some observation. Our main research question is:

Does the students' understanding of basic quantum mechanical concepts

improve when these concepts have a firm ground in an observation?

To answer this question, we designed several assignments related to observation. As a starting point we took the idea of energy levels, and the structure of the hydrogen atom. The assignments were tried out in the QP course. In designing the assignments we made use of the Van Hiele level scheme, of which a short description is given in the next section.

Van Hiele level scheme

Van Hiele (1986) experienced difficulties in teaching geometry at high school in the early 1950s. It was then customary to teach geometry starting from axioms and definitions. Van Hiele noticed his students had difficulties with this approach. When his students finally seemed to understand the subject, they would remark that it was not so difficult after all, and would ask him why he explained it with so much difficulty. This made Van Hiele think he and his students were initially speaking a different language. Elaborating on this idea, Van Hiele introduced the notion of levels of thinking. Each level is characterized by a different language with its own quality of reasoning. When student and teacher do not reason at the same level, they will have difficulties understanding each other.

According to Van Hiele, learning starts with an observation of some kind, involving one, or more of our senses. Van Hiele focused on visual observations and called the first level of thinking the *visual level*. This does not mean only vision is used at this level: in principle all senses are involved. At this level we name objects by global identification.

At the second level, the *descriptive level*, we start naming properties of the objects we observe. We describe the objects from the first level, and agree on a common description. It is

a characteristic of this level to have a network of relations, which was lacking on the first level.

After we have made a complete enough description of our problem, we might want to reflect on this description. In doing so, we are moving to the third level of thinking: the *theoretical level*. For instance: it might occur to us that some of the relations we have found depend on each other. We might also notice that a certain relation follows from a set of other relations. Or perhaps some relation is in contradiction to some set of other relations. At this level we try to find a complete, but minimal theory.

The level scheme is hierarchic: the second level is concerned with elements of the first level, and the third level is concerned with elements of the second level. When moving to a higher level, we learn a new language that makes it possible to speak about the previous level. In this sense it is impossible to move to a next level, without learning a new language. In teaching, it might sometimes appear as if a student is at the theoretical level, because he uses words from that level. This should not have to be the case. A student has attained a certain level only when his *reasoning* has qualities of that level.

Experimental setup

This research is structured following a developmental research approach, in which the researcher teams up with the teacher(s) to research and improve education. The research is initiated by learning difficulties students might have, or difficulties in teaching the teacher might experience. As a problem analysis, the researcher first analyses the current educational practice. Insight from such an analysis is used to redesign the education for the next year. This incremental approach enables the researcher to test hypotheses concerning the observations he has done. Based upon the results of new design these hypotheses have to be adjusted in a next round.

The actual experiment consists of interventions; trying out a new assignment, or exercise in a problem solving session. The researcher has certain expectations of such an intervention. If, and how these expectations come true inform the researcher of the (in)correctness of his hypotheses. These expectations are written out before the intervention takes place. Such written out expectations are sometimes called a scenario. To check the scenario, various kinds of data are collected during and after the teaching: audio recorded student discussions, surveys, and student work.

Educational design

The lecturer of the QP course had ideas to give more attention to the history of quantum mechanics, and the experimental connections. This gave us the opportunity to research our main question. The lecturer wanted to start his introduction with Heisenberg's formulation of quantum mechanics. Heisenberg found the Bohr model unsatisfactory because of the appearance of non-observable terms in the theory (e.g. the position the electron). He set out to design a "theoretical quantum mechanics founded exclusively upon relationships between quantities which in principle are observable" (Heisenberg, 1925).

The first two lectures were spent on a historical overview of the Heisenberg picture, its connections with Schrödinger, the Bohr model of the atom and the correspondence principle. Following the Van Hiele level scheme, we set up three assignments for the problem solving sessions to give body to the Heisenberg view: the existence of energy levels, the Bohr model of the atom, and the Rydberg–Ritz combination principle. In this paper we will focus on the assignment on the existence of energy levels. We wanted to let students find out that the idea of energy levels is much more fundamental than the Bohr model that tries to explain their existence.

In the assignment students are presented with the spectrum of hydrogen; the visual part, and a more extensive table with frequencies of the entire spectrum (Figure 1). They are asked to plot the spectrum using *Mathematica*, and describe the structure they see. Next, students have to choose a suitable numbering for the spectral lines, and use this numbering to find a fit to the data. This way, students should arrive at the Rydberg formula:

$$f_{mn}=Rc\bigg(\frac{1}{m^2}-\frac{1}{n^2}\bigg),$$

where *f* is the frequency of a given spectral line, *R* the Rydberg constant (for hydrogen), *c* the speed of light, and $m \le n \le N$. From there they hypothesize the existence of energy levels to explain this formula, and rewrite it in a more general form (Einstein–Bohr relation):

$$hf_{mn} = E_m - E_r$$

where h is Planck's constant. Looking at the structure of the Rydberg formula we ask students to propose a function for the energy levels of hydrogen.



Figure 1 Visual part of the hydrogen spectrum, with wavelengths given in nm (top), and the table with the data of the full spectrum. This data was taken from: http://physics.nist.gov/PhysRefData/ASD/

Results

The assignment started with some simple exercises to let students become familiar with the presented spectral data of hydrogen (Figure 1). Students had to convert wavelength to frequency, and make a plot of the spectral lines (Figure 2 shows the result). They then had to identify the visual part of the spectrum in this plot, and they had to name the different parts (visual, infra-red, and ultra-violet). This did not pose too many problems.

	•				•	• • •	
5		10	15	20	25	30	 10 ¹⁴ Hz

Figure 2 *Mathematica* plot students had to make of the data from the table in Figure 1. The horizontal axis gives the frequency in 10^{14} Hz.

Next students had to characterize the hydrogen spectrum (Figure 2), and try to articulate what pattern they could discern. A typical answer of a student⁷:

The pattern in the [...] series is that most left in the series, the distance between two points is large, and becomes smaller the further you go to the right. Also the distance between the series becomes smaller the further you go to the left...

⁷ More extensive protocols of student responses are available from: www.science.uva.nl/~lkoopman/GIREP2006/

For this student it is clear that there is a certain pattern in the spectral lines. She is able to correctly describe what she sees, and thereby gives a definition of what a series is. Therefore she is reasoning at the descriptive level.

In a discussion with the teacher, another student remarks:

- Such a series, that the energy becomes higher, and then the distance between
 - the spectral lines becomes smaller. Or is this not what is meant?

His remark is visual (on ground level) in the sense that he says what he is seeing. From a remark later on it becomes clear that with 'energy' this student means the energy of the emitted photon. He uses the non-visual term 'energy level'. This makes the teacher think this student is already able to reason with energy levels, and describe the spectrum with it. In his answer, the teacher uses non-visual terms: 'But do you choose a certain fixed ground level where it jumps to? Because you always have two energy levels.' The teacher is reasoning with the theoretical level in mind. The student however continues to speak in a visual manner. Later, this student explicitly says that he is not able to give the relation between the lines he sees, and the energy levels he has heard about. Teacher and student speak on a different Van Hiele level here. After 15 minutes, the teacher notices that the student identifies the spectral lines with the energy levels. Something similar has also been noted by Zollman *et al.* (2002). We furthermore see that students do not have to be at theoretical level when they use words from that level.

The assignments continues by suggesting to the students that the spectrum shows several series of points (Lyman, Balmer, Paschen), and asking them to identify these series by selecting the spectral lines for each series. To be able to find a fit, we suggest the students to number the lines in the series, and give a motivation for this numbering. This was straightforward:

I think from left to right is most easy (from low to high [frequency]) if there would be any more lines somewhere, then they are probably in the part where the lines are closest, there the lines are difficult to keep apart. If a new line would be found, it would just get a higher number; otherwise you would have to call it 0, or even -1.

Most students made a similar choice, and gave a similar motivation. There are two possible numberings, and students give an argument what numbering to choose. This is another characteristic of the descriptive level.

Fitting the data appeared to be more difficult. We expected students to try some functions with which they could describe the Lyman series. Students were not able to find the expected fit. The reason is that students actually had to do two things: find an appropriate function, and realize that a whole number could be added to the argument of that function. This is because the numbering is in principle arbitrary. It might as well have started from two. Because of this, a fit with the most straightforward function 1/x gave a good result, but with

the 'correct' function $1/x^2$ the fit is very bad. The difficulty here is that we have made an assignment where students have to find there own way to solve a given problem (e.g. "try to find an acceptable fit to the data"). In Van Hiele terms this is called a free orientation assignment. However, students are probably not ready for this, and need an assignment where they perform specific tasks that should point them in a certain direction (e.g. "try the function $1/x^2$ for the function $1/x^2$ for the function."

 $1/x^2$ for the fit"). This is a socalled guided orientation assignment.

In finding a theoretical explanation for the discreteness of the spectrum, we hoped students would arrive at an expression for the energy levels in the hydrogen atom. We gave them the following two hypotheses to explain the hydrogen spectrum:

- 1. An atom can have any possible energy, but can only emit this energy in certain discrete portions, given by the function f(n,m) found [in the exercise] above,
- 2. An atom can only have specific energies, and because of this it can only emit this energy in certain discrete portions, given by the function f(n,m) found [in the exercise] above.

These hypotheses are both expressions on theoretical level: they do not contain observable terms, and they state an absolute relation between newly introduced theoretical terms. Students had to choose the most reasonable hypothesis, and give a motivation for their choice. Most students opted for the second hypothesis, but were unable to motivate their choice,

simply stating that it gives a better explanation. These students were unable to reason on a theoretical level. One student gave a smart motivation for the second hypothesis:

If an atom could have any possible energy, there should be a way to reach this energy. If only discrete energy steps are possible, then coming from a certain energy level, you cannot reach an arbitrary other energy level. The reasoning in [hypothesis] one is thus in contradiction with itself.

This answer might be considered a theoretical argument: the student searches for consistency of the theory of energy levels.

Most students were not able to give an expression for the energy levels of hydrogen, based on their expression for the spectral lines. The transition from descriptive to theoretical level could thus not be made.

Conclusion

We described an intervention on the spectrum of hydrogen, leading to the hypothesis of energy levels. In the discussions with students we have shown to be able to describe difficulties in terms of the Van Hiele levels of thinking. For instance, student and teacher have difficulties understanding each other when they reason at a different level. In the development towards the theoretical level, students might not be able to make the transition from one level to the other. Such a transition is a discontinuous jump. In the assignment on the energy levels, we had difficulties letting students make the transition from descriptive level to theoretical level. Most students were able to reason on a descriptive level.

One might say that the assignment on the energy levels is rather trivial. At high school students have already learned that an atom has energy levels. Our results show however, that students are not able to connect this theory with the experimental data. This is an indication that they do not fully understand what the theory should describe. If students already not fully understand a theory the teachers find trivial, what should we expect from more complex theories, like the quantum theory in general? This question is a motivation for the next phase of this research. We would like to extend this approach to see whether we can apply it to more difficult concepts, like the wave function, superposition, and measurement.

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Interpreting Diffraction Using the Quantum Model

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Abstract

In previous researches we designed and implemented an educational path to construct the theoretical quantum mechanical model, following the Dirac vectorial outline, in the secondary school. In analysing the phenomenon of polarisation students are introduced to quantum concepts and construct their new ideas about: the peculiar concept of state; the superposition of states; the meaning of incompatible observables; the basic formalism of vectorial space. Interpreting diffraction, within the conceptual framework of our proposal, constitutes simultaneously an extension, a potentiality and

a strengthening of the proposal itself.

In the context of the Italia-Slovenia Interreg III Project, we designed a didactical model for teachers in order to interpret diffraction patterns. The development of this model starts from the quantum model of polarization constructed above. The diffraction model is based on the identification of mutually exclusive potentialities of photon transmission through a single slit. The pattern derived from the diffraction model is in good agreement with the experimental one, in the Fraunhofer approximation.

Introduction

In the panorama of proposals concerning the teaching of quantum mechanics in secondary schools (Phys. Educ., 2000; Am. J. Phys, 2002) we may identify a stream that adopts the strategy of analysing specific phenomenologies to construct quantum concepts. This makes reference to the Dirac's vectorial description of quantum states (Dirac, 1958; Sakurai, 1985) and hinges upon the discussion of the principle of quantum linear superposition, as a founding principal of the new theory, and also pays attention to the role played by formalism in attributing meaning to physical entities (Feynman, 1965; French, 1975; Toraldo di Francia, 1975; Ghirardi et al., 1995; Pospiech, 2000; Holbrow et al., 2002).

Our proposal concerning the teaching of quantum mechanics is linked to this stream (Ghirardi et al. 1997; Michelini et al., 2000, 2001). The phenomenology of optic polarisation constitutes a privileged context for the constructing of a bridge from classical to quantum physics for successive levels of conceptualisation from the phenomenological laws studied in the laboratory, to their analysis in an ideal single photon context, to their discussion for the construction of the concept of state and of superposition, and to the mathematical formalisation at the base of interpretation (Cobal et al., 2002; Michelini et al., 2002; Michelini, Stefanel, 2004).

The research conducted on-site have demonstrated the effectiveness at secondary school level of a strategy based upon the development of logical arguments by the students in a coherent exploration of different interpretative hypotheses, constructed by students itself in the context of our educational path. The results have shown that the students grow more competent in the quantum descriptions of phenomena through the concept of state, with a sufficient mastering of the basic formalism and an understanding of its conceptual role (Michelini et al., 2001; 2004).

The use of concepts in diverse contexts consolidates the learning process, while extending its depth. We therefore pose the objective of building a model for the quantum description of optic diffraction without relying upon classical interpretation. The choice is dictated by the cultural and applicative relevance of such a phenomenology (Bohr, 1961), and by the availability of on-line sensors, which facilitate its exploration and provide the opportunity for facing an interpretation not limited to the case of bi-dimensional vectorial spaces. In the context of the Italia-Slovenia Interreg III Project and Italian national Project PRIN-Fis21, we designed a didactical model in order to interpret diffraction patterns. Below we present the case of a single slit diffraction.

The phenomenology of the single slit diffraction

With two on-line sensors, one of position and one of light intensity, we may acquire the distribution of light intensity produced by a single slit diffraction process, as illustrated in Figure 1 (Corni et al., 1993). Analysing the distribution as a function of position we recognize that:



D1) $I_{max} \propto 1/D^2$, the maximum value of the distribution Imax is proportional to the inverse of the square of the distance D between the slit and the sensor

D2) the distribution of light intensity on the screen is described, under Fraunhofer's conditions, by the equation:

$$I(\theta) = I_o \left(\frac{senz}{z}\right)^2$$
 where $z = \frac{\pi a sen \theta}{\lambda}$ (1)

and a is the slit width, λ is the light wave length, θ is the angle that individuates the point on the screen with respect to the centre of the distribution (Figure.2). θ is related to the transverse position y on the screen by the simple relation y=D tg θ (θ =0 \rightarrow y=0 corresponds to the centre of the distribution).

Fig. 2. The photons laser beam incides the slit A on S1 screen. The photons transmitted impact upon a screen S2, distant D from S1, where we observe the diffraction pattern. We detect the impacts number with a matrix of detectors R_o , $R_{\pm 1}$... $R_{\pm m}$, each one of which determines a channel of impact located between $y_{i-1} e y_i$. The oval indicates the activation of the i-th detector.



Experiments at low intensity

The same distributions I=I(y) that are obtained at high intensity, may be obtained when we work with light beams with an intensity so low that the diffraction figure could be interpreted as the result of single photon impacts on the screen. The experiment was effectively proposed in an old film of PSSC (King, 1973), but may also be attempted using simulations (Figure 3).

A quantum mechanical interpretation of the phenomenon implies that we may obtain the distribution of intensity I=I(y) of the diffraction as a result of the impact of single photons on the screen.

The situation under analysis is schematised in Figure 2. The photons of a laser beam incides on a first screen S1, with a slit of width a. The photons transmitted are collected by a screen S2 which shows the figure of diffraction. S2 is subdivided in 2m+1 channels of impact, each one located between y _{i-1} e y_i, or rather substituted by a matrix of 2m+1 detectors Ri, with i=0,±1, ±2,...,±m.

The equation:

$$f(y_i) = I(y_i)/I = N(y_i)/N$$



provides the probability $P(y_i)$ of a single photon impact on the i-th channel.

Interpretative hypotheses

The distribution $I=I(y_i)$ that we observe is the result of the interaction of photons with the slit, in that: if we cover the slit, we observe nothing on the screen; if we remove S1, only a luminous spot may be seen on the screen. This interaction does not depend upon the material of which the screen S1 is made, in such that the distribution I=I(y) depends solely upon the value of a, which is easy to recognise in the experiment.

In addition we must exclude any hypothesis of a deterministic construction of the image, as when the photons that impact upon a channel Ri of the screen are, for example, among those that have passed through the upper/lower semi-slit; in obscuring the other half of the slit (Figure 4) we modify the entire figure and not only the part with which we are dealing. We must then conclude that, $P(A1R_i) \neq P(AR_i)$, where $P(A1R_i)$ e $P(AR_i)$ are probabilities that a photon will impact on the channel Ri, which respectively passes through the slit A1 or the entire slit A. Similarly, we reach the conclusion that $P(A2R_i) \neq P(AR_i)$ and, in addition, that $P(AR_i) \neq P(A1R_i) + P(A2R_i)$, with an analogous significance of the symbols.





This expresses the fact that the distribution produced from a slit of width a is not the sum of the distributions obtained with each of the two semi-slits of width a/2.

We may conclude that all the photons that reach S2 utilise (in some way) the entire slit A to propagate from the source to S2.

The quantum interpretation

The case of polarisation may help with the carrying out of the analysis. If a beam of polarised photons incides on two aligned birefringent crystals, one direct and the other inverse (Figure 5), the propagation of the photons occurs in a superposition of states. Each one of these corresponds to different potential alternatives where each

Fig. 5. Suggestion provided in the case of polarisation.



photon may be detected, interposing a screen for example on one of the paths (ordinary or extraordinary), which correspond with cases of mutually exclusive states of orthogonal polarisation.

If we apply the same criteria to the case of photons transmitted through the slit A, the vector \mathbf{W}_{ARi} , which represents the state <passage through A – detection in R_i ?, must be a linear combination of \mathbf{W}_{A1Ri} and \mathbf{W}_{A2Ri} , vectors of state in which the photon may be detected in R_i if A2 or A1 are obscured:

$$\mathbf{W}_{\mathrm{ARi}} = \frac{1}{\sqrt{2}} \left(\mathbf{W}_{\mathrm{A1Ri}} + \mathbf{W}_{\mathrm{A2Ri}} \right)$$

with the hypothesis that the slit is uniformly illuminated.

To find the probability of detecting the photon in R_i we evaluate the square module of the scalar product

$$\mathbf{u}_{\mathrm{Ri}} \cdot \mathbf{W}_{\mathrm{ARi}} = \frac{1}{\sqrt{2}} \left(\Psi_{1\mathrm{Ri}} + \Psi_{2\mathrm{Ri}} \right),$$

with: $\Psi_{jRi} = \mathbf{u}_{Ri} \cdot \mathbf{W}_{AjRi}$ and \mathbf{u}_{Ri} vector which represents the detection of the photon in R_i . The slope of the distribution of light intensity on the screen is given by:

$$P(AR_i) = |\mathbf{u}_{Ri} \cdot \mathbf{W}_{ARi}|^2 = 1/2 |\Psi_{1Ri} + \Psi_{2Ri}|^2$$

This is a non-uniform distribution, which is, however, completely different from expression (1). In the case in which we consider a sub-division of the slit in n parts (Figure 6), the written formulas may be easily generalised thus obtaining a better fit of experimental distribution:

$$\mathbf{W}_{ARi} = \frac{1}{\sqrt{n}} \Sigma_{n} \mathbf{W}_{AjRi} \quad \text{and} \quad \mathbf{u}_{Ri} \cdot \mathbf{W}_{ARi} = \frac{1}{\sqrt{n}} \Sigma_{n} \Psi_{jRi}$$
$$P(R_{i}) = |\mathbf{u}_{Ri} \cdot \mathbf{W}_{ARi}| 2 = (1/n) |\Sigma_{n} \Psi_{jRi}|^{2} \quad (2)$$

Given that for large D the experimental distribution depends upon $1/D^2$, it is expected that $\Psi_{jRi} \sim \phi(r_{jj})/D$, with $\phi(r_{jj})$ proportional to a momentum autofunction, in fact the momentum p of photons is sufficiently well defined that it can be assumed: $\phi(r_{jj}) \sim \exp[(i p r_{jj})/\hbar]$, with r_{jj} module of the vector **AR**_i and \hbar is the Plank constant. With these positions in the relation (2), it is obtained:

$$P(R_i)=(1/n)|A/D|^2 \cdot |\Sigma_n \exp[(i p r_{jj})/\hbar]|^2$$
.

Passing to the limit for $n \rightarrow \infty$, we have:

$$P(\mathbf{R}_{i}) = 1/n |\mathbf{A}/\mathbf{D}|^{2} \left(\frac{sen z_{i}}{z_{i}}\right)^{2} \propto I(\theta_{i})/I_{max} \qquad \text{with} \quad z = \frac{ap}{2\hbar} sen \theta_{i}$$

This distribution of probability reproduces the experimental distribution under Frahunhofer's conditions (1).



Fig. 6. The construction of the mutually exclusive elementary alternatives.

Conclusions

With a model based upon the principle of superposition, the analysis of mutually exclusive alternatives for photons passed through a slit allows a quantum mechanic interpretation of diffraction.

We have built a description of diffraction that identifies all possible states of superposition that, with the same weight, intervene to determine the state of superposition that represents the propagation of photons. We therefore determine the probability of detecting photons in the different zones of a screen reproducing the distribution of intensity that is detected experimentally under Frauhunhofer's conditions. In this sense the result may be considered as his interpretation.

The model is easily extendible to the phenomenon of the interference of a thin surface.

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Learning Astronomy

Pre-Service Physics Teachers' Mental Models of the Moon and Some Lunar Phenomena

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Abstract

The purpose of this study was to identify Turkish pre-service physics teachers' knowledge and understanding of the Moon, Moon phases and other lunar phenomena. Results illustrate that pre-service teachers might enter to science teacher education programs with various nonscientific knowledge. The pre-service physics teachers participated in this study had various flawed, incoherent and incomplete mental models about the Moon and some lunar phenomena. Their most widespread misconceptions, which were emerged from their understanding of reflection, scattering, Kepler's Law, angular momentum, relative size, motion, distance, and gravitation, were related to the following lunar phenomena: moonrise and moonset, seeing the same phase of the Moon, the Moon's effect on tides, appearance of the same phase of the Moon at the same time all over the world, magnitude change in the appearance of the full Moon, and the number of lunar eclipse.

Introduction

Students' misconceptions are known to cause difficulties for their learning of physics concepts. If physics teachers also have some non-scientific conceptions, these difficulties may become bigger handicap for students to learn physics.

The reform movement in teacher education programs in Turkey since 1998 has increased the concern of whether pre-service teachers themselves understand the concepts well enough. Therefore, investigation of science conceptions is an important issue for teacher educators.

Learners' Conceptions of the Moon and some Lunar Phenomena

Learners' conceptions of the Moon and some lunar phenomena have been a central focus for various studies from different countries (Barnett and Morran, 2002; Parker and Heywood, 1998; Summers and Mant, 1995; Suzuki, 2003; Taylor, Barker and Jones, 2003; Trumper, 2003; Zeilik, Schau and Mattern, 1998), Suzuki (2003), for example, aimed to determine Japanese pre-service teachers' ideas about the Moon and seek how to engage them in thinking together about the Moon. According to his results, pre-service teachers had some knowledge of the Moon; however, they assumed that the Moon could only be seen at night. Furthermore, Trumper (2003) asked multiple choice astronomy questions to 645 primary school student teachers in Israel. He presented the following results: a considerable number of students' reasons for seeing the same side of the Moon was that the Moon did not rotate on its axis and, some of the students claimed that the Moon revolved around the Earth but not around the Sun. Research shows the following commonalities in people's understanding of the Moon and some lunar phenomena: the Moon does not rotate on its axis, the Moon is the only cause of tides on the Earth, the Moon is seen only at night, and the Moon does not revolve around the Sun.

Some research has been conducted to determine learners' conceptions of Moon phases only (Callison and Wright, 1993; Rider, 2002; Stahly, Krockover and Shepardson, 1999; Trundle, Atwood and Christopher, 2002). Callison and Wright (1993), for instance, determined pre-service elementary teachers' scientifically inaccurate views about Moon phases before the instruction and concluded that some of them kept inaccurate views after the instruction. Research indicates that the most common misconception of the cause of Moon phases held by the participants is 'Earth's shadow falling on the Moon'.

One of the reasons for the difficulty in learners' conceptions of lunar phenomena is their naïve knowledge mostly based on their observations of astronomical events (Samarapungavan, Vosniadou and Brewer, 1996; Trumper, 2003). As Bisard, Aron, Francek and Nelson (1994) presented in their research, although naïve views decreases as the age increases, misconceptions frequently pass on into adulthood. Unfamiliarity with optics (Parker and Heywood, 1998) and limited understanding of some

physics concepts such as light, relative size, motion and distance (Treagust and Smith, 1989) are also difficulty in learning the Moon-related events.

Purpose of the Study

The purpose of this study was to identify Turkish pre-service physics teachers' knowledge and understanding of the Moon, Moon phases and other lunar phenomena.

Methodology

Qualitative research method was designed for this study because it helped the researcher to better understand the process of constructing meaning and describe what those meanings were (Bogdan and Biklen, 1998).

Participants

The participants in this study were 36 pre-service physics teachers. Their ages ranged from 22 to 27; of whom, 15 (42%) were males. They graduated from eleven different universities and all had obtained a degree in physics. All of them studied reflection, scattering, gravitation, Kepler's laws, and angular momentum as parts of both high school and undergraduate physics curriculum. They also studied Moon phases and lunar eclipse as parts of elementary science curriculum.

Instrument

The questionnaire including 20 factual (e.g., "When the Moon rotates on its axis, what direction does it follow?"), explanation (e.g., "The Moon appears yellow or orange, when it is near the horizon; and almost white, when it is near the zenith. Why?") and generative (e.g., "Assume that the Sun was just rising on the eastern horizon. The Moon was full and it could be seen someplace in the sky. Where would the Moon be?") questions was used to identify the pre-service physics teachers' mental models clearly and thoroughly. The type of the questions was determined as open-ended to be able to evaluate the participants' reasoning behind their answers. While some of these questions had been taken from the research by Barton (2001), Rider (2002) and Trundle et al. (2002), some of them had been prepared by the researcher (Ogan-Bekiroglu, in press).

Data Collection

The primary data source was the participants' written responses to the questions. Content validity of the questions was judged with two science educators. Moreover, the participants' responses indicated that all the questions were assessed what they had been intended to assess.

Data Analysis and Categorization of Mental Models

Conceptions are proposed as mental models in this study. Mental model is a representation of knowledge as a set of interrelated propositions that are embedded in a structure (Chi and Roscoe, 2002). The pre-service physics teachers' mental models generated in response to the lunar phenomena might be representations of their naïve physics as a result of their causal observations and experiences with the world, and their misconceptions as a result of inconsistencies between their naïve knowledge and scientific knowledge. Therefore, their mental models were categorized based on the work done by Chi and Roscoe (2002) as correct, complete flawed, incomplete correct, flawed, and incoherent. If both the response and the reasoning behind it were consistent with the scientifically accepted perspective, it was coded as 'correct mental model' (e.g., "yes, we always see the same face of the Moon because the Moon rotates once on its axis at the same rate it revolves once around the Earth"). If the response was correct at the first sight but the reasoning behind it was not consistent with the scientifically accepted perspective, it was coded as 'complete flawed mental model' (e.g., "yes, we always see the same face of the Moon because the Moon does not rotate on its axis"). If the response included some correct scientific terminology but the explanation was not sufficient, it was coded as 'incomplete correct mental model' (e.g., "the reason for halo around the Moon is thin clouds in the atmosphere that behave like a curtain"). If the response was not consistent with the scientifically accepted perspective, it was coded as 'flawed mental model' (e.g., "the reason for halo is thin clouds around the Moon"). If the response, whether it was scientific or not, was given, but the reason for the answer was neither given nor clear, it was coded as 'incoherent mental model' (e.g., "refraction of the sunlight results halo"). If the respondent stated that she/he did not know the answer or left it blank, the response was coded as 'none'. The data was re-examined a few times to detect any response that did not fit into one of the mental model categories.

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Results and Discussion

The pre-service physics teachers' mental models were presented with frequency values. The full details of the responses made to each question showing what was accepted as correct mental model and what was described as flawed mental model were given in another study (Ogan-Bekiroglu, in press). Some of the most widespread conceptions are shown in Table 1 and discussed in this paper.

The pre-service physics teachers had various flawed mental models of the Moon. Only two participants (6 %) explained why we always see the same face of the Moon. Fifty-three percent of the participants' responses were right at the first sight. However, when their reasoning was investigated, the majority of them showed spontaneous reasoning (Viennot, 2001) that the Moon did not rotate on its axis. This result was consistent with the result emerged from the research by Trumper (2003) whose participants were also pre-service teachers.

On the other hand, almost all of the participants had scientific knowledge of the cause of Moon phases. This finding was not similar with the ones presented by other researchers who also worked with pre-service teachers (Callison and Wright, 1993; Dai and Capie, 1990; Trundle, et al. 2002). The reason for this difference might be the major of the participants of this study, which was physics.

Likewise, most of them had the correct mental model of lunar eclipse occurrence.

Although one-half of the pre-service physics teachers knew that rising time of the Moon changed per day, none of them could give any reason.

More than half of the participants (64 %) had the idea that the Moon traveled around the Earth in a circular orbit. Students' mental models are often influenced by their prior observations or experiences and these prior experiences can occur inside and outside of the classroom from the following sources: textbooks, observation of the Moon and discussions with others (Stahly et al., 1999). Possibly, the reason for the pre-service teachers' this flawed mental model is the assumption generally used in problem solving in physics.

A large amount of the pre-service teachers (61 %) left blank the question related to the changes in orbital velocity of the Moon during its revolution around the Earth. Only 12 pre-service teachers (33 %) could explain that on account of conservation of angular momentum, the velocity of the Moon increases when it comes to the closer position to the Earth during its revolution. These results illustrated that even though the pre-service teachers solved various quantitative problems related to angular momentum and Kepler's Laws in their undergraduate education, they might have not learned the concepts meaningfully.

The pre-service teachers' mental models of tides were not complete with regards to the scientific explanation. They disregarded the effect of the Sun's gravitational force on tides. None of the responses about the tidal effect were consistent with the scientific perspective, that is, tidal effect is the biggest when it is full Moon or new Moon, and the smallest when the Moon appears first or last quarter. Half of the participants had the flawed mental model that the more visible the Moon, the more tidal effect on the Earth. Their sense of mechanism can be described as Ohm's p-prime (phenomenological primitive) (diSessa, 1993).

Only 28% of the participants had correctly explained why the Moon appeared yellow or orange, when it was near the horizon; and almost white, when it was near the zenith. Unfortunately, none of them had correct mental model of the reason for a halo around the Moon.

Similarly, only two pre-service physics teachers (6 %) could explain that the Moon's orbit is inclined to the ecliptic by an average of 5-6° and eclipses only occur when the Sun, the Earth and the Moon are aligned; consequently, the Moon behind the Earth, the Earth, and the Sun come on the same plane only twice a year. Dove (2002) highlighted that diagrams could create confusions. Her conclusions about the standard textbook illustrations of Moon phases are very similar with those in Turkish textbooks. Many elementary textbooks depict the Moon orbiting the Earth in an anti-clockwise direction and four, or eight moons are shown in their phase positions each half illuminated by the Sun's rays beaming in from the left or the right. The diagram is misleading because the Moon's orbit is shown aligned with the ecliptic, whereas if this was true there would be a solar eclipse every new Moon and a lunar eclipse every full Moon (Dove, 2002).

A large number of the pre-service physics teachers had incomplete correct mental model about the Moon's reddish-copper glow during a total lunar eclipse.

Results from analysis of the questions about magnitude change in the appearance of the full Moon, a halo around the Moon and the color of the lunar eclipse indicated that the pre-service teachers had some partial knowledge related to some concepts of optics, such as reflection and refraction, but because of the missing pieces in the propositions, these propositions cannot be interrelated with the presented situations.

Conclusion and Suggestion

Results illustrate that pre-service teachers might enter to science teacher education programs with various non-scientific knowledge. The pre-service physics teachers participated in this study had various flawed, incoherent and incomplete mental models about the Moon and some lunar phenomena. Their most widespread misconceptions, which were emerged from their understanding of reflection, scattering, Kepler's Law, angular momentum, relative size, motion, distance, and gravitation, were related to the following lunar phenomena: moonrise and moonset, seeing the same phase of the Moon, the Moon's effect on tides, appearance of the same phase of the Moon at the same time all over the world, magnitude change in the appearance of the full Moon, and the number of lunar eclipse. Because one of the purposes of pre-service science teacher education is to raise pre-service teachers' own knowledge and understanding of scientific phenomena Sharp (1996), we, as teacher educators, should apply some instructional strategies that give pre-service teachers an opportunity to be aware of their misconceptions and the appropriate categories so that their incorrect beliefs could be removed and flawed mental models could be repaired.

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Phenomenon	Category	Mental Models and Reasoning	Freq.(%) n=36					
Same face of	Correct	We always see the same face of the Moon. Reasoning: The Moon rotates once on its axis at the same rate it	6					
the Moon		revolves once around the Earth.						
	1.Com.Flaw	We always see the same face of the Moon. Reasoning: The Moon does not rotate on its axis.	33					
	2.Com.Flaw	We always see the same face of the Moon. Reasoning: Both the Moon and the Earth rotate on their axes in the	17					
		same period.						
	3.Com.Flaw	We always see the same face of the Moon. Reasoning: The Moon rotates on its axis from south to north.	3					
	1.Flawed	We do not always see the same face of the Moon Reasoning: Both the Moon and the Farth rotate on their ares	36					
		in different periods						
	2.Flawed	in ujjereni perious.	3					
		We always see the same area on the Moon, if we always look at it from the same place on the Earth. Reasoning:						
	None	Both the Moon and the Earth rotate on their axes in the same 24-hour-period	3					
		Do not know or blank						
Lunar Eclipse	Correct	A lunar eclipse occurs when the Earth gets between the Sun and the Moon. Reasoning: In this position, the	72					
		Moon passes through the shadow of the Earth.						
	1.Flawed	A lunar eclipse occurs when the Moon gets between the Sun and the Earth. Reasoning: In this position, the	22					
		Moon cannot reflect the sunlight and we cannot see the Moon.						
	2.Flawed	A lunar eclipse occurs when the Sun gets between the Moon and the Earth. Reasoning: In this position, we						
		cannot see the Moon because of the Sun.	- 0					
Day to day time	1.Incoherent	The Moon does not rise everyday at the same time. No reason has given.	50					
difference in	2.Incoherent	The Moon rises everyday at the same time. No reason has given.	28					
Moonrise	None	Do not know or blank	22					
Moon's orbit	Correct	The moon travels around the Earth in an elliptical orbit.	36					
shape	Flawed	The moon travels around the Earth in a circular orbit.	64					
Changes in the	Correct	The velocity of the Moon changes during its revolution around the Earth. Reasoning: On account of	33					
orbital velocity		conservation of angular momentum, the velocity of the Moon increases when it comes to the closer position to						
of the Moon		the Earth during its revolution.						
	Flawed	The velocity of the Moon is constant during its revolution around the Earth. Reasoning: All phases of the Moon	6					
		have the same period.						
	None	Do not know or blank	61					
Tides	Correct	Both the Moon's and the Sun's gravitational forces cause tides on the Earth.	19					
	Incom.Corre	The masses of tides is the Mass's analitational forme	72					
	None	ne reason of tides is the Moon's gravitational force.	9					

Table 1	Dra carviaa nh	voing tanghars'	montal models	and reasoning
	rie-service pir	ysics leachers i	memai mouels	and reasoning

Correct: Correct mental model, Com.Flaw: Complete flawed mental model, Incom.Corre: Incomplete correct mental model, Flawed: Flawed mental model Incoherent: Incoherent mental model, None: No Response

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		Tuble 1, cont. Treservice physics teachers mental models and reasoning					
Phenomenon	Category	Mental Models and Reasoning	Freq.(%) n=36				
Tidal effect	1.Flawed	The tidal effect on the Earth is the biggest when it is full Moon, smaller when the Moon appears first or last quarter and the smallest when it is new Moon. Reasoning: Visibility of the Moon is directly proportional with the tidal effect. The more visible the Moon, the more tidal effect on the Earth.	53				
	2.Flawed	The tidal effect on the Earth is the biggest when the Moon appears first or last quarter and the smallest when it is full Moon or new Moon. Reasoning: Tidal effect is proportional to the inverse square of the distance. When we see the Moon in a first or last quarter, it is in the nearest position to the Earth in its elliptical orbit and tidal effect is the biggest.	33				
	3.Flawed	The tidal effect on the Earth is the biggest when it is new Moon, smaller when the Moon appears first or last quarter and the smallest when its is full Moon. Reasoning: When it is new Moon, the Sun and the Moon have tidal effects on the Earth from the same direction; during the first and last quarter, the Moon is more closer to the Earth than the Moon is full or new; and when it is full Moon, the Sun's and the Moon's tidal effects are in appearing directions and any tidal effects.	8				
	4.Flawed	The tidal effect should be the same in every phases of the Moon. Reasoning: The tidal effect is related to the distance between the Earth and the Moon.					
Changes in the colour of the Moon	Correct	When the Moon is near the horizon, the reflected sunlight coming from the Moon travels more distance in the Earth's atmosphere and short wavelength rays are scattered more during this travel. Therefore, the Moon appears vellow or orange when it is near the horizon	28				
1110011	None	Do not know or blank	72				
Halo	1.Incom.Cor 2.Incom.Cor 1.Flawed 2.Flawed Incoherent	The reason for halo is water particles in the atmosphere that refract the sunlight. Thin clouds in the atmosphere behave like a curtain and result halo. The reason for halo is particles breaking away from the Moon and reflecting the sunlight. The reason for halo is thin clouds around the Moon. Profession of the sunlight results a halo.	22 22 6 9 30				
	None	Do not know or blank	11				
The number of lunar eclipse	Correct	The Moon's orbit is inclined to the ecliptic by on average five to six degrees. Eclipses only occur when the Sun, Earth and Moon are aligned. The Moon behind the Earth, the Earth and the Sun come on the same plane only two times a year.	6				
	1.Flawed	Lunar eclipse occurs every month but we can only see two of them because they occur at night, other lunar eclipses occur in the daytime and we cannot see them.	6				
	2.Flawed None	Lunar eclipse occurs two times a year because of the Earth's rotation on its axis.	3				
		Do not know of blank	86				

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the lunar eclipse	2.Incom.Cor	A water particle in the atmo	nhara disparsas t	ha whita light into cor	monents		11
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	None	Refraction of the sumght					25
		Do not know or blank					
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model	Incoherent:	Incoherent	mental	model,	None:	No	Response

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Learning about Waves and Sound

A Pedagogical Approach to Modelling Electric Conduction in Solids.

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Abstract

We present a pedagogic approach aimed at modelling electric conduction in metals, built by using the modelling environment Net Logo, and describe some related activities. The reported examples have been experimented during the laboratory courses of the Italian Pre-Service School for Physics Teacher Education (S.S.I.S.).

Introduction

Computer modelling and simulation tools can help physics teachers to focus on relationships between macroscopic and microscopic properties of matter, enabling students to model systems directly at the level of their individual constituent elements and their interactions, in order to understand emergent macroscopic properties.

The benefits of multi-agent simulations for understanding how a variety of complex behaviours derive from simple interactions of local agents are today well known [1]. A core feature of multi-agent simulation environments is that students can apply a small number of rules to capture fundamental causality structures underlying behaviours in a range of apparently disparate phenomena.

Building a model by thinking in terms of individual agents appears to be intuitive, particularly for the mathematically uninitiated [2, 3]: the related pedagogic activities may be centred on an approach to learning physics that follows the same steps than learning a new language [4].

Here we present some pedagogic procedures aimed at relating measurements of electric properties of conductors with "virtual experiments" built by using NetLogo [5]. Models of both classic and quantum electric conduction in metals, such as the Drude-Lorentz and Sommerfeld ones, have been implemented. The different model predictions about the resistivity vs. temperature dependence and some related parameters have been related to experimental results.

The reported activities have been experimented during the laboratory courses of the Italian Graduate School for Physics Teacher Education (S.S.I.S.).

Experimental results

Resistivity vs. temperature measurements have been performed in the context of an education project aimed at studying electric conduction properties of solid conductors, semiconductors and superconductors [6].

Measurements have been performed by using an electronic board allowing to take data of the electric current circulating in a sample when it is subject to a given voltage, as a function of the sample temperature. The board is designed to study the resistance of high T_c superconductor samples but we have modified it to take also measurements with conductors and semiconductors. Here we report only the data taken in conductors.

The resistance data at low temperature values are taken by suspending the metallic sample in a thermally insulated container and letting it cool under the action of liquid nitrogen vapours placed in the container. Current and voltage, as well as temperature data have been collected by using digital multimeters connected to the electronic board, as shown in figure 1.

Fig. 1. The experimental apparatus.



Figure 2 shows data taken by using a thin copper wire, of length L = 0.5 m and cross sectional diameter $d = 2 \times 10^{-4}$ m.



Fig. 2. Resistivity vs. temperature in a copper wire.

A linear dependence of resistivity from temperature is evident, as expected for a conductor in the range of analysed temperatures.

From the well known resistivity vs. temperature formula

$$\rho = \rho_0 \left[1 + \alpha \left(T - T_0 \right) \right]$$

and from the linear fit parameters reported in figure 2, it is easy to obtain an estimate of the temperature coefficient α in copper. ρ_0 is the resistivity at $T_0 = 273$ K.

$$\alpha = (4.07 \pm 0.04) \times 10^{-3} \frac{1}{K}$$

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This value is in accordance with the expected value for α in copper [7]. These results are in good agreement with other measurements [8] aimed at help students to

Modelling

Microscopic models describing and explaining the experimental results have been implemented by using classical and semi-classical models implemented in NetLogo.

The main pedagogical purposes of such simulations can be summarized as follows:

- to emphasize the fundamental concepts related to electron motion and electroncrystal lattice interactions as key concepts to understand the electron transport phenomena and the effects of temperature variation;
- to supply a deep understanding of microscopic conduction mechanisms and their modifications due to the temperature, emerging from different and more refined microscopic models of metals.

The implemented models share some characteristics with well known historical models and will be described in the following.

The first and simplest model, fitting some of the conduction properties of metals, is the 'Drude-Lorentz model'. It considers the electrical conduction as due to a "gas of free electrons" moving through a lattice of fixed ions, against which they collide. If an electric field is applied, electrons, of charge e and mass m_e , are subject to an acceleration eE/m_e . The whole effect of collisions is viewed as a viscous force, counterbalancing the electrical force and maintaining constant the velocity of electrons.

If n_e represents the number of free electrons in a unitary volume and v_d is the drift velocity of the electrons, i.e. the mean velocity of the electrons in the field direction, the metal resistivity can be written as:

$$\rho = \frac{E}{n_e e v_d} \tag{1}$$

The mean time τ between collisions is expressed in term of the electrons' mean thermal velocity v_m and of the total cross-sectional area A for the electron-ion scattering.

$$\tau = \frac{1}{n_e v_m A} \tag{2}$$

The drift velocity and the metal resistivity can be related to τ by the formulas:

$$v_d = \frac{eE}{m_e}\tau, \qquad \rho = \frac{m_e}{n_e e^2 \tau}$$
(3)

The crucial point in this microscopic representation ("relaxation time approximation") lies in the interpretation of v_m and A. Our simulations use three different interpretations or 'pictures': the 'Drude-Lorentz' one, the 'Full classic' picture and the 'Semi classic Sommerfeld' picture, described in the next section.

Model implementations

The models have been implemented by using NetLogo 3.0.2 and NetLogo 3D preview 1 [5]. We consider a small volume of copper containing the same numbers (about 100) of free electrons and ions arranged in a regular three-dimensional crystal lattice. Electron and ions are modelled as small elastic spheres of given mass and dimension. Electron-electron and ion-electron Coulomb interactions are not considered. Consequently, the trajectory of an electron is a straight line/an arc of parabola, in the absence/presence of electric field E.

Although the simulation runs in a three dimensional space, the system can be visualised both in three dimensions (figure 5) and in a two-dimensional projection (figure 6).

Fig. 5. NetLogo 3-D visualisation of electrons moving in the ion lattice.



Fig. 6. A two-dimensional projection of the 3-D space and the simulation result: the graph of electron drift velocity as a function of time.



The user can choose one of the three models previous described, set the temperature and the electric field strength and perform two different types of 'virtual experiments': a) by varying the field strength at a constant temperature; b) by varying the temperature at a constant field strength. The program output is the electron drift velocity as a function of time. When the drift velocity reaches its steady value it can be acquired and the resistivity value is calculated (1). With several values of resistivity corresponding to different temperature a graph of ρ as a function of T is built.

The detailed implementation of the three models presents some differences, both statistical and dynamical, reflecting the different characteristics of these models.

Drude-Lorentz model

Here the electrons have a velocity distribution in accord to Maxwell-Boltzmann statistics. Then, to a given temperature T, v_m corresponds to the mean square root velocity v_{rms}

$$v_m = v_{rms} = \sqrt{\frac{3kT}{m_e}}$$

The lattice ions are considered at rest with a radius equal to ion radius (for copper, $r_0 = 0.361$ Å).

The electron-ion collisions are treated as perfectly elastic and no dissipation mechanisms are considered. For not too high electric field strengths (below 100 V/m), the system reaches a steady state condition in which the dynamical quantities, such as drift velocity and mean relaxation time, are constant (figure 6). By changing the system temperature (i.e. the value of v_{rms}), a plot of resistivity as a function of T can be obtained, as shown in figure 7.

Fig. 7. Resistivity vs. temperature graph obtained by implementing in the simulation the Drude-Lorentz model.



'Full classical' model

In this model we take into account the ion oscillations by assuming that they depend on the temperature. From theoretical considerations it is possible to assume that the effective maximum oscillation amplitude is proportional to $T^{1/2}$.

The effective ionic radius r is assumed to be equal to the maximum oscillation amplitude. Electron–ion collision is assumed to be elastic, with exchanges of energy and momentum. We also consider a dissipation mechanism in the model, by keeping ions in equilibrium with a thermal bath at constant temperature.

Figure 8 shows the resistivity vs. temperature data obtained in the temperature range 100K - 700K. As expected, results of this classical model are in discordance with the experimental results (see figure 2).

Fig. 8. Resistivity vs. temperature graph obtained by implementing the full classical conduction model within the simulation.



Semi-classical Sommerfeld model

The implementation of this model differs from the previous ones since here the quantum nature of electrons is taken into account by considering the Fermi-Dirac statistic. Then, in the temperature range of interest, the distribution of electrons velocity is almost independent from the temperature. As in the previous models, the electron-ion interactions are considered perfectly elastic.

Fig. 9. Resistivity vs. temperature graph obtained by implementing the semi-classic Sommerfeld model within the simulation.



The result obtained with the semi classical Sommerfeld model (figure 9) are in good agreement with the experimental data, reported in figure 2 : the linear dependence of ρ from temperature is found and physical parameters, like the temperature coefficient and the resistivity values at T = 273K, are close to the ones obtained from the real experimental data.

Discussion and conclusion

Our models are based on a few fundamental rules of atomic interactions that exhibit emergent behaviours reproducing important aspects of the properties of materials, as electric conductivity.

There are several features of our pedagogical approach that may contribute to student learning. In our simulations, the same underlying computational model appears in different contexts and gradual modifications of the model are outlined. This provides several advantages:

- students gain familiarity with different representations and ways in which electrons behave and interact with nuclei;
- the model parameters can be set by the student, in the same way in which they interact and control the experimental parameters;
- the macroscopic properties of the model emerge from the details of the atomic-scale interactions in just the way that the corresponding properties emerge in real atoms.

A preliminary analysis of prospective teachers worksheets allows us to infer that laboratory activities, scaffolded by modelling, can improve students' learning about actions and interactions of individual objects resulting in emergent system properties.

Prospective teachers showed a better understanding of the difference between simply describing a situation in terms of equations and interpreting it on the basis of mechanisms of functioning. After the lab part of the workshop, prospective teachers showed a renewed attitude to search for interpretative models, even involving microscopic interactions, explaining why a phenomenon develops in a given way or some specific experimental results are obtained.

Acknowledgements

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Modelling Mechanical Wave Propagation by Connecting Microscopic Properties and Emergent Behaviours

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Abstract

In this paper we report a didactic approach to mechanical wave propagation based on both measurements and modelling of wave properties in solids by using MBL and a simulation tool widely used in undergraduate physics courses, as well in pre-service teacher education activities. Considerations about observed modifications in prospective teachers' attitude in utilising experiments and modelling to build pedagogical activities are discussed.

Introduction

Waves are phenomena that we constantly observe in our everyday life. Moreover, it is well known that a correct understanding of wave propagation is important in the education of physicists and engineers, as it can facilitate to figure out more complex subjects like physical optics, quantum mechanics and electromagnetic radiation.

In this paper we present a didactic approach to mechanical wave propagation based on measurements and modelling, by using Microcomputer Based Laboratory and the Interactive Physics environment [1]. In particular, the propagation speed of longitudinal wave pulses along metallic rods is measured and a model of longitudinal wave propagation in a mass-spring linear chain is built in order to analyse the propagation of pulses in it. Simulation results are used to give evidence of the dependence of pulse speed in the linear chain from some relevant parameters of the model.

Experiments and modelling activities have been built in the context of a workshop on Mechanical Wave Laboratory of the two-year graduate teacher education program of Palermo's University. Some considerations about observed modifications in trainee teachers' attitude in utilising experiments and modelling to build pedagogical activities are discussed.

Experimental results

In order to calculate sound speed values in metallic rods, we performed measurements of travelling times of longitudinal wave pulses. The experimental apparatus is based on the reflection of pulses at the rods' ends. A metallic rod, of length L, is hung on non-conductive elastic bands below another rod supported by stands. A d.c. power supply is connected through a MBL voltage sensor to one end of the suspended rod and to a metallic body (an hammer head) arranged to collide with the rod, as in figure 1.

Figure 1. The experimental apparatus. The voltage sensor detects the d.c. power supply voltage when the hammer head is in contact with the rod.



If the electric circuit is closed by making the colliding body coming in contact with the rod's left end, a voltage signal is detected by the data logger. The body hits the rod's end,

exerting an impulse on it. If the body is sufficiently massive, it remains in contact with the rod while a compression pulse travels along the rod, reflecting at the open right end of the rod. When the reflected pulse returns to the rod's left end, the contact is broken, actually triggering the end of signal detection.

The signal duration is related to the distance travelled by the pulse, and from the known length of the rod it is possible to calculate the pulse speed.

Figure 2a reports a typical signal detected by the MBL system when an hammer head, of mass equal to 398.0 ± 0.1 g hits a brass rod, of length $L = 3.010 \pm 0.001$ m and cross-section diameter $D = 1.00 \pm 0.01$ cm.

Fig. 2. a) Typical signal detected by the voltage sensor in the experiment of figure 1. The MBL sampling rate is 50000 samples/second. b) Enlargement of the signal. Error bars are equal to $2 \cdot 10^{-5}$ s.



The travelling time τ , is easily measured by considering the time interval corresponding to the constant part of the peak. From figure 2b, we obtain $\tau = (1.78 \pm 0.02) \cdot 10^{-3}$ s. More measurements have been performed by using brass rods of different lengths and cross-sectional diameters, as well as aluminium rods. Figure 3 reports travelling times obtained with rods of different lengths and D = 1.00 cm for brass and aluminium rods.

Fig. 3. Time interval vs. distance travelled by the pulse, in brass (Set 1) and aluminium (Set 2) rods of different lengths and cross-sectional diameter equal to 1.00 cm. Continuous lines are experimental data fittings.



Each point of figure 3 is the mean value of 10 measurements, error bars are standard deviations of mean values. Similar results are obtained for sets of rods with different D [2], showing that sound speed is independent from the rod section.

Table 1 resumes the sound speed values measured in aluminium and brass rods. The uncertainties are calculated by using the errors on the slope of the fitting lines, reported in figure 3.

Tab.	1.	Measu	red	acou	stic	wave	speed	in	aluminium	and	brass	rods	and	accepted	values as
		repor	ted i	n han	dbo	oks [3].								
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Rod material	Sound speed (m/s) (measured)	Sound speed (m/s) (accepted)
Aluminium	4980 ± 80	5000
Brass	3440 ± 50	3480

Modelling and simulation

Simple microscopic models of the solid rods have been implemented in Interactive Physics (IP) in order to find simple explanations of sound speed difference in various metals. Elastic rods have been modelled as a collection of mass-spring systems interacting each other and the chain microscopic parameters (mass value, m, and spring elastic constant, K,) are related to the macroscopic parameters (Young modulus, Y, and density, ρ) by the well known [4, 5] relations:

$$K = Yd$$
$$m = \rho d^3$$

where d is the inter-atomic distance.

A typical IP model is shown in Figure 4. The relevant parameters d, m and K in the case of a model representing an aluminium rod have been chosen as follow:

$$d = 2.5 \cdot 10^{-10} m;$$
 $m = 4.5 \cdot 10^{-26} Kg;$ $K = 18 \frac{N}{m}$ (4)

In order to simply simulate the cubic face centred molecular structure of aluminium, d has been taken as the mean value of the inter-atomic distances. m and K have been chosen in accordance to accepted [2] values of ρ and Y in aluminium.

The first chain particle, A in figure 4, is moved by applying a longitudinal Gaussian pulse. The movement of a particle of the chain can be analysed. We denote with B the seventh chain particle, whose displacement is confronted with that of particle A one. From the delay between the instants A and B start to move, it is possible to have information about the propagation speed of the pulse along the chain.

Fig. 4. Interactive Physics model of a rod, represented by a mass-spring linear chain.



Figure 5 reports the displacement of A (black bold line) and B (grey lines), as functions of time for three different values of m and of K. a denotes the case in which values for m, d, K are the ones reported in (4); in b K remains unchanged, while the m is doubled; in c K is halved and m is doubled with respect to case a.

Fig. 5. displacement of the first chain particle (black bold line) and of the seventh particle (grey lines), as functions of time for three different values of the chain particle mass and of the elastic constant. a: K = 18 N/m and $m = 4.5 \times 10^{-26}$ Kg; b: K = 18 N/m and $m = 9.0 \ 10^{-26}$ Kg; c: K = 9 N/m and $m = 9.0 \ 10^{-26}$ Kg.



A quick look to figure 5 allows to immediately recognise a lower propagation speed of the pulse in cases b and c with respect to case a. A more detailed analysis of the delay times between displacement curves of particles A and B in each case gives values of the pulse speed as a function of the elastic constant and of the particle mass. Figures 6 and 7 show the square of pulse velocity as a function of K and of the reciprocal of m, respectively.

Fig. 6. Square of pulse velocity as a function of the chain's spring elastic constant. Continuous line is the one best fitting data.



Fig. 7. Square of pulse velocity as a function of the reciprocal of the chain particle mass. Continuous line is the one best fitting data.



The linear relationships between the plotted variables in both cases give evidence of a dependence of the pulse speed from K and m that can be written as

$$c = \alpha \sqrt{\frac{K}{m}}$$

where α is a constant whose value can be found from the linear fit parameters reported in figures 6 and 7. The obtained value for α is in good accordance with the value of *d* used in simulation and reported in (4). The resulting expression for the pulse velocity in the linear chain is, then:

$$c = d\sqrt{\frac{K}{m}}$$

in accord to the well known mathematical expression for the speed of a pulse in a linear chain in the limit of non-dispersive medium [5].

Discussion and conclusion

The experimental activities and the simulations here discussed have been performed by a group of Student Teachers (STs) in the framework of a Pedagogical Laboratory of Mechanical Wave Propagation.

A detailed discussion about what STs learned by experimental activities is reported elsewhere [2]. We here concentrate on some relevant insights gained by STs through the integrate use of MBL and modelling activities.

STs performed experiments and ran the simulations by themselves, actually experiencing the same learning tools and environments they are supposed to use with their future pupils. Then they discussed the pedagogical use of the materials and built teaching/learning sequence (TLS) addressed to high school pupils. The sound speed measurements performed by using the proposed experimental method stimulated many discussions about the physics of wave propagation. The experimental evidences introduced STs to the problem of elasticity in real bodies and the subsequent building and running of simulations allowed them to deepen understanding and link the macroscopic experimental results with a mechanism of inner functioning.

The analysis of simulation results of the simple linear chain model made STs better understand the role of relevant model parameters in finding the speed of pulses propagating in the chain. The possibility to vary model parameters like the mass of chain particles and the elastic constant, representing the interaction between the particles, made STs better understand the meaning of physical variables like the 'inertia' and the 'elasticity'. Discussions during the laboratory activities evidenced that many STs had not really understood the physical meaning of correlation between propagation speed of a pulse and these physical variables, although they had studied mechanical waves in their degree courses. These STs' behaviours, together with their interest in performing the experiments, allow us to make some conclusions about their understanding of wave physics as well as the role of modelling. Many of them developed interesting discussions and reflections about the role of laboratory and modelling activities in teaching and showed to better understand the difference between simply describing a situation in terms of equations and interpreting it on the basis of mechanisms of functioning.

A preliminary analysis of prospective teachers worksheets allows us to infer that the implementation of laboratory activities, scaffolded by modelling, can improve students' learning about actions and interactions of individual objects that result in emergent system properties.

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Physics Teacher Pedagogical Content Knowledge for Modelling Mechanical Wave Propagation

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Abstract

This paper addresses the question on how to develop prospective teachers' Pedagogical Content Knowledge in the field of modelling mechanical wave propagation. We focus on the central issue of the relationships between observable phenomena and their interpretation and/or explanation in terms of microscopic characteristics and behaviours of media. This paper reports an empirical study developed an a course for pre-service teacher preparation.

Introduction

We describe an empirical study about the teaching of physics modelling in a Graduate Program for Pre-service Teacher Education. The study involves the structure and content of the Physics Education Course aimed at preparing prospective teachers to learning approaches focused on modelling procedures. Our research hypotheses concern the teaching methods to be implemented in the course in order to make the Student Teachers (STs) aware of the strategies to put into action in facilitating the process of construction of models relevant to the understanding of mechanical wave propagation phenomena.

Some researches [1, 2] pointed out that science teachers today show difficulties in introducing and sustaining a authentic model-based curricula and that the new demands and requirements of modelling curricula place on teacher education must be explicitly addressed. They involve that:

- teachers' subject content knowledge should include a comprehensive understanding of the nature of *what a model is* [3];
- teachers' Pedagogical Content Knowledge (PCK) .[4, 5] should include their ability to develop good teaching models in order to support learning [6];
- teachers' competencies should include the conduction of modelling activities and the understanding of how their students construct their own mental models.

Empirical study

The present study involves the redesigning, implementing and evaluating the structure of a course for physics teacher education aimed at making explicit the procedures connected with model construction and at expanding pre-service teachers' PCK.

The course has been structured as a workshop covering 80% of the whole class time. Two experienced high school teachers participated, as tutors, in some phases of the workshop. They had already tested in their classrooms some of the proposed experiments as well as the modelling activities and evaluation materials.

Data involved in this study result from the analysis of STs' worksheets and other empirical material prepared by STs during the workshop, as well as of the tutors' logbooks.

At the end of the workshop STs were required to prepare a "teaching proposals" for their apprenticeship, by defining in detail small teaching-learning sequences for high school classroom activities. They were supposed to pick out some experiments and computer activities, among those performed during the workshop, and to organise them in Learning Units by preparing pupils' guides for classroom work. The analysis of these proposals supplied also relevant evidences about the STs' construction of an adequate PCK.

Participants

Thirty-five STs, graduated in physics or mathematics or engineering attended the course. All STs have studied physics in their University degree programs for at least two courses. These

consisted of lectures concerning the theory and applications required to solve quantitative problems, without any laboratory activity. A few STs had some teaching experience for limited periods of time.

The initial STs' physics knowledge have been evaluate through the results to the admission test, assessing the knowledge of the basic topics of Physics. In particular, the majority of our STs showed a good knowledge of basic concepts about mechanical wave propagation. In fact, more than 70% of STs gave a satisfying definition of mechanical wave, and showed a good knowledge of the mathematical definition of wave as well as of the physical meanings of the different parameters characterising a wave.

The workshop design

The workshop was designed to supply a teaching/learning environment aimed at:

- making STs experience the same learning environments they are supposed to realise in their future classrooms;
- supplying STs with pedagogical tools suitable to the purpose of conceptualising physics models and gaining the abilities connected with modelling procedures;
- involving STs in activities stimulating hands-on learning and metareflection through negotiation in collaborative inquiry.

I) Review of pupils' naïve re-presentations.

This phase was aimed at making STs aware of some common conceptions, held by high school pupils, concerning the functioning of some phenomena. STs were involved in activities concerning the analysis of pupil answer sheets of questionnaires and of literature papers about pupil ideas and reasoning about waves propagation's phenomena.

II) Observation of everyday phenomena.

This phase was aimed at pointing out connections between spontaneous models and everyday phenomena. STs performed observations using materials easy to find (ropes, slinky,...) and analysis of videos concerning everyday phenomena involving wave propagation. STs were stimulated in finding the involved physical variables, inferring their relationships and predicting behaviours.

III) Experiments and data analysis.

STs were involved in performing quantitative and semi-quantitative experiments and data analysis, using cheap and easily available materials and commercial sensors (with computer interfaces), for open-ended investigations. The activities were aimed at the mastery of abilities connected with the building the experimental protocol and performing experiments.

Experimental work involved the measure of sound speed in solid rods [7] and direct comparisons of sound speed in solid rods and air. Figure 1 gives an example.

IV Modelling

STs were involved in activities aimed at building physical models able to describe and interpret observations and experiments as well as at finding relationships between experimental data and hypotheses supporting the dynamical models explaining the analysed processes. They were directly involved in dynamical modelling by using appropriate software (simulations and spreadsheets) and in the re-analysis of the various experiments, explanations as well as predictions, on the basis of features of the proposed models.

Modelling activities were developed in order to formalize the dependence of propagation speed from the medium characteristics. As a consequence, the slinky was modelled by some masses (one for each coil) connected with springs without mass (see figure 2a) and propagation of transversal and longitudinal pulses were analysed in the simulated models.



The simulation allows the user to modify the values of masses and elastic constants and to analyse variations of the pulse propagation speed. Simplified models of solids, related to linear chains of masses and springs (see figure 2b) were analysed. Analogies between the previous simulated model and the qualitative models of solids were developed, by looking at the relationships between spring elastic constants and solid compressibility as well as particle masses and solid densities [8].

Modelling involved also the analysis of simulations visualising sound pulse propagation in a column of air-particles. STs were stimulated to observe pulses generated by a piston moving at the end of a long column of gas particle and to find analogies with longitudinal waves generated at the end of a long spring. It was analysed how a forward movement of the piston (see figure 3) produces an increase of density and pressure in the initial region that propagates along the column with a velocity that can be calculated as a function of gas pressure and gas density. In the same way, a backward movement of the piston produces a rarefaction pulse in the initial region that propagates along the column.

Simulations were supposed to supply representations of air motion where a displacement from density or pressure equilibrium is propagating. By looking at the motion of particle layers, STs were stimulated to connect particle motion with generator motion and point out how the air (or medium) properties influence the propagation speed.

V) Metareflection

During this last phase, STs were involved in the preparation of reports defining teaching-learning sequences for high school classroom activities by justifying the pedagogical reasons of the chosen activities. The main objective of this phase was in stimulating the awareness of the learning strategies and self-regulation skills applied in the various phases of the work and how these strategies and skills are related to learning goals [9]. STs were stimulated to decompose and make explicit the knowledge to be taught from two different perspectives:

a) the involved reasoning models (physics models and/or everyday/practical explanations derived from informally observed every-day contexts);

b) the finding of identifiable instances where a concrete pedagogic action was employed for a particular reason, for example in response to a learning difficulty or a known naïve representation.



In all the phases, our approach focused on the process of modelling as a set of procedures (thinking and doing) to find descriptions and explanations of phenomena. Our teaching strategy supported STs' learning by using different kinds of questions aimed at stimulating them to elicit their representations and mainly to make explicit how the different models are useful to describe and/or explain phenomena.

Results and conclusions

Some preliminary results obtained by the analysis of STs' worksheets and the prepared teaching-learning sequences show that the workshop had been effective in guiding STs toward the construction of an appropriate PCK. To allow STs to experience the same learning environments they were supposed to implement in their future classrooms showed a two-fold advantage: they could directly verify their pedagogical validity and, at the same time, make use of them to master the physics subject at the level of conceptual understanding that they will need to develop in their future students.

The STs' behaviours during the initial part of the workshop showed that, although mechanical waves was a familiar topic for all the STs, they had not been involved in elaborating and investigating the topic in a context focusing the direct analysis of experimental facts (or phenomena) without any direct reference to formulas and/or laws to apply. As a consequence, it was evident that their understanding of the analysed physics topic was usually weak; their university courses supplied some sets of formulas that they were able to superficially manipulate in order to solve some quantitative problems, without deeper understanding of the fundamental concepts involved. They were not able to relate ideas and concepts learned in their physics courses to real-world contexts while, as the workshop went on, they appeared more and more able to apply their knowledge in programming and performing experiments and in pointing out relationships among variables and explanations.

Our research identifies the importance of a thorough and coherent knowledge of subject matter and offers general guidelines in designing teacher education programs aimed at the development of PCK. In our view, the value of PCK lies essentially in its relation with

specific topics. Therefore, PCK is to be discerned from general pedagogical knowledge on the one hand, and from subject-matter knowledge on the other. Our study gives insight into the ways physics teachers can transform their knowledge of waves not only to stimulate pupil understanding of this topic but also to gain a better understanding of the topic. It also shows ways to provide prospective teachers with a knowledge base which enables them to teach specific topics in a more effective and flexible way.

Acknowledgements

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The speed of sound measurement

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Abstract

The speed of sound can be easily measured indoors by using two microphones and a fast recording device such as a digital storage scope. However, the measurements I shall present require only one microphone and yet they enable us to measure the speed of sound as well as to confirm (at a qualitative level) three additional properties: 1) speed vs. temperature dependence, 2) gas composition dependence and 3) to establish that gas is a non-dispersive medium.

Furthermore, a cheap flexible plastic tube, a microphone, a PC and shareware software (such as CoolEdit [1, 2]) motivate the students to also perform these experiments at home. I intend to carry out these experiments during my lecture. Adapting a tube which is commonly used to install electrical wires in the walls, one can detect two signals after a clap is produced. The first signal comes directly to the microphone while the second one comes with a few hundredths of seconds delay as it travels through the tube. The software enables us to resolve time intervals even a hundred times smaller. As the tube is cheap, I propose to use a tube at least 8 meters long. To establish the temperature dependence of speed and of sound, the tube can be filled by warm air simply by using a hair-drier. The change in the speed of sound as a function of gas composition can be easily produced by emptying a helium-filled balloon into the tube. As the average kilo molecular mass of such air is reduced, the speed is increased.

Introduction

The teaching of waves and sound could be enhanced by many experiments in the classroom. Furthermore, these experiments stimulate the students to explore wave and sound phenomena by themselves. How can one show and tell something new about such a popular theme? This paper will present some ideas how to improve the teaching of physics and to stimulate the students.

Experimental set-up

The speed of sound can be easily measured indoors by using two microphones and a fast recording device such as a digital storage scope. However, the measurements I shall present require only one microphone. The main object is the tube (approx. 10 m long) which is commonly used to install electrical wires in the walls (Fig. 1). We must also have a microphone, a PC and shareware software (such as CoolEdit [1, 2]), and something to produce an *attaca sound*, like a clap. I will use two hammers.

Fig. 1. Plastic tube, microphone, hammers and "assistant's hand".



Measurements

A microphone is placed near one end of the tube while the other is covered by an assistant's hand. The recording is started and we produce several claps at the upper opening of the tube (see Fig.1). Next the assistant removes his hand. We stop the recording and analyze the sound file. Fig. 2 shows a typical result. It is obvious which part of the signal is produced by the sound which traveled through the tube. As we know the length of the tube, we can easily measure the speed of sound. Certainly, the result is not as accurate as with some more technical methods. The main problem is the length of the tube – which radius takes into account. Such simple experiments enable us to measure the speed of sound as well as to confirm (at a qualitative level) three additional properties: speed vs. temperature dependence, gas composition dependence and to establish that gas is a non-dispersive medium.

Fig. 2. The two signals were measured consecutively. The upper one was recorded while the assistant's hand covered one opening of the tube. They are displayed together (as left and right channel signal) in order to make the difference more obvious. The time delay is about 28,5 ms.



The length of the tube is 9,8 m. The time delay between the direct signal and the secondary signal ("bypass signal", i. e., signal, which traveled through the tube) is 0,0285 s. The speed of sound calculated from these measurements is 344 m/s.

Let us explore gas composition dependence first. A helium balloon is emptied into the tube. One must be careful to place in the tube as much helium as possible. After a certain amount of helium is in the tube, the result shows shorter time. This is in accordance with the well known formula for the speed of sound:

$$c = \sqrt{\frac{\kappa RT}{M}}$$

The average kilo molecular mass of the gas composition inside the tube is not 29 kg any more; it is reduced and therefore the speed is increased, what is proven by shorter time as shown on Fig. 3.



Fig. 3. The sound signal and the "by pass signal". The delay is now only 16 ms. There is a certain amount of helium inside the tube and as expected, the time decreased.

This is the basis for explaining "helium voice". It is nice and amusing to hear how helium changes the resonant frequency of the human vocal tract, causing a higher-pitched, cartoon-character sound. Nevertheless, we must warn the students that helium is an inert gas that is lighter than air and can be inhaled only briefly without risk of death. However, only a few small inhalations are completely safe [3]!

However, let us talk about more familiar phenomenon. All musicians, including amateur ones, are aware of the problem of brass and woodwind instruments. We must warm them up in order to achieve a stable intonation. If the instrument is tuned when it is at room temperature and not at "working temperature", it is going to sound out of tune after a few tones played. The temperature affects the speed of sound. Certainly, it also effected by the length of the instruments and therefore lowers the pitch; however, this effect is extremely small. By warming up the air in the tube (instrument) the speed of sound is increased about a percent. Such a change in the speed raises the frequencies of the instrument. According to the equation:

$$c=f\lambda$$
,

the pitch rises for the same amount, one percent in our case. And such a change is heard almost by everyone. The listener concludes the musicians are out of tune. To establish the temperature dependence of speed of sound, the tube can be filled by warm air simply by using a hair-drier. The measurement proves that the speed of sound is greater by higher temperature (Fig. 4).



Fig. 4. The upper measurement is made by room temperature air while the lower one shows shortening of the delay because the air temperature is higher.

Conclusion

There are many possibilities to measure the speed of sound. The presented set-up enables some variations which help teachers to explain some phenomena that students know from everyday life. I have presented two of them: "helium voice" and the tuning of brass and woodwind instruments. No doubt an innovative teacher will find some additional use of this set-up. Last but not least, we all hope to activate students' curiosity and to give them some hints for their home experiments, which can be carried out with cheap equipment.

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Comparative Study of Sound Processing Computer Applications for its Usage as Learning Tools in Wave Physics and Acoustics

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Abstract

Computer has become a relevant piece of equipment in the physics laboratory, not only as a powerful computing means, but also as an active component of some experimental arrangements. In the acoustics laboratory, suitable software is essential as part of the laboratory equipment.

In this paper we compare three software applications with each other, in order to determine which is the most suitable one for the considered learning activities and which practical advantages has each one in front of the others. The compared applications are Audacity, WaveLab and Cool Edit 2000, today rebranded under Adobe Audition, the most known ones in our college.

The specific learning activities considered range from observing and studying the relationship between fundamental frequency and pitch, up to experimenting with the spectral synthesis of timbers.

The evaluation process has been performed using each computer application in the same set of learning activities. In this way, we graded the ease of use offered by each computer application for each considered activity. In addition, an overall grade for every application was calculated after establishing appropriate weights for each activity. This weighted mean grade has to be seen as a guiding value, not as a statement of "the winner", since the decision about which computer application would be the most suitable in every day's practice depends on the particular learning activity planned.

1. Introduction

In addition to a very efficient simulation means, personal computer became a relevant piece of equipment in the physics laboratory very early, not only as a powerful computing device, but also as an active component of some experimental arrangements (e.g. Collings and Greenslade, 1989, Maps, 1993, Preston and Good, 1996, and Dunham, 2002).

In the acoustics laboratory, suitable software is essential as part of the laboratory equipment (e.g. Karjalainen and Rahkila, 1998, and Arai, 2003).

2. Research question

Following three software applications for sound processing are the most known ones in our college: Audacity (release 1.2.4, from SourceForge.net), WaveLab (r. 4.0c, from Steinberg Media Technologies) and Adobe Audition (here r. 2.0, rebranded upgrading of the former Cool Edit, from Adobe Systems Inc.). Figure 1 contains examples of screen displays (wave form and harmonic spectrum) of each program. See References (Sourceforge.net, Steinberg Media Technologies and Adobe Systems Inc.) for web sites

The question raised is which one of them is the most suitable as learning tool in wave physics and acoustics.





Audacity

WaveLab

Adobe Audition (former 'CoolEdit')

		a)	b)	c)	d)	e)	f)	g)
		Fundam.	Fourier	Timbre,	Timbre,	Amplitude	Formation	Synthesis
		frequency,	analysis	wave	growth	and	of beats	of
		pitch and		form and	and	loudness		timbres
		wave form		spectrum	decay			
1.	Importing sound samples from CDs	0.8	0.8	0.8	0.9	0.8	0	0
2.	Tailoring of wave form <i>t</i> -axis display	0.9	0.3	0.9	0.9	0.2	0.6	0.2
3.	Tailoring of wave form y-axis display	0.3	0.2	0.9	0.9	0.9	0.3	0.2
4.	Altering single digital samples	0	0.3	0.3	0.3	0.2	0	0
5.	Procedure for obtaining spectra	0.3	1.0	1.0	0.2	0	0	0.5
6.	Modifying FFT settings	0.2	0.8	0.8	0.2	0	0	0.2
7.	Reading of spectrum peak frequencies	0.4	0.9	0.2	0	0	0	0.2
8.	Tailoring of spectrum display	0.2	0.6	0.6	0	0	0	0.2
9.	Generating and mixing sound tracks	0	0	0	0	0	1.0	1.0
10.	Exporting to MP3	0	0	0	0	0	0.5	0.5

Table 1. Factors expressing the degree of involvement of the single features (denoted 1 to 10) provided by sound processors in the implementation of the learning activities considered in the text (a through g) (0 = no involvement, 1.0 = essential).

Table 2. Efficiency and ease of use offered by each computer application in the single operations 1 to 10, graded on a scale from 0 (no possibility) to 10 (highly efficient and easy to perform).

		Audacity	WaveLab	Adobe Audition
1.	Importing sound samples from CDs	2 (¹)	10	9 (²)
2.	Tailoring of wave form <i>t</i> -axis display	8 (3)	7 (4)	10
3.	Tailoring of wave form y-axis display	5 (⁵)	8 (6)	10
4.	Altering of single digital samples	10	10	3 (7)
5.	Procedure for obtaining spectra	9 (⁸)	8 (%)	2 (¹⁰)
6.	Modifying FFT settings	10	6 (¹¹)	10
7.	Reading of spectrum peak frequencies	10	9 (¹²)	9 (¹³)
8.	Tailoring of spectrum display	3 (¹⁴)	8 (¹⁵)	8 (¹⁶)
9.	Generating and mixing sound tracks	10	7 (¹⁷)	0 (¹⁸)
10.	Export to MP3	8 (¹⁹)	10	10

Remarks:

(¹) Only indirectly possible (and very cumbersome) through external programs like Windows Media Player. Stereo-to-mono conversion also very cumbersome.

⁽²⁾ The same as for WaveLab, but with less flexible previous playback.

 $\binom{3}{3}$ Only one scale type (in sec.). Time range not adjustable (nor displayed) numerically.

(⁴) Zooming is also easy, but not directly adjustable to screen. Time range not adjustable (nor displayed) numerically.

(⁵) Graph and background colors not modifiable. Scale only in fractions of 1 and in dB.

(6) Scale labeling in dB not correct for y = 0.

 $\vec{(1)}$ No possibility of altering single samples directly (only through 'copy and paste').

 $\binom{8}{1}$ Need to snap to zero-crossings every time after selecting the analyzed wave form range.

⁽⁹⁾ Somewhat cumbersome (two steps are needed every time: the commands 'Spectrum analyzer FFT' and 'Analyze selection').

(¹⁶) Modification of wave form selection not possible!. Snap to zero-crossings complicated. The need for using the command 'Explore selection' every time is a possible source of errors.

(¹¹) Modification of the FFT settings 'analysis block size' and 'smoothing window' and the frequency scale type somewhat cumbersome.

(¹²) Not as easy as with Audacity, but still easy, thanks to the possible enlargement of a given frequency range with the mouse.

⁽¹³⁾ Not as easy as with Audacity, but still very easy (level in dB displayed directly).

(¹⁴) Frequency scale labeling incorrect! Colors and type of graph not modifiable. dB scale range not modifiable. (Exportable data too rough to be useful.)

(¹⁵) Deficient default display (e.g. scales poorly legible). Frequency scale labeling correct, but irrational. (Exportable numerical data too rough to be useful).

(¹⁶) Default display with very dark colors. Colors not modifiable (graph color: only to a very limited extent). dB scale range not modifiable.

(¹⁷) Generating a track of a given frequency and mixing of tracks somewhat cumbersome (requires 'Select>All' and 'Paste special').

(¹⁸) Procedure unfeasible or too complicated for our purposes (in spite of the powerful –but not simple– handling of previously recorded sound tracks).

(¹⁹) Need for downloading and installing the free codifier LAME, according to the easy instructions provided in the Audacity web site itself (they work!).

3. Assessment criteria

To answer the foregoing question, we have set following specific learning activities related to our course on wave physics and acoustics:

- a) Studying the relationship between fundamental frequency and pitch of a sound through the wave form;
- b) Studying the composition of a periodic oscillatory phenomenon as sound in relation to harmonics (and noise);
- c) Studying the relationship between the wave form or the acoustic spectrum and the perceived timbre of a sound, based on the preceding activity;
- d) Observing the effect of the initial and final wave forms of a sound (growth and decay) on the perceived timbre;
- e) Studying the link between the wave form amplitude and the perceived loudness of a sound;
- f) Experimenting with the formation of beats through the generation of two freely adjustable frequencies;
- g) Experimenting with the synthesis of timbers from simple harmonic sound waves.

The first column of Table 1 lists ten operations offered by sound processors in general, which are more or less involved in the learning activities considered. The table gives an estimate of the degree of involvement according to our experience. These operations include also different preparatory tasks, as well as the obtaining of graphic materials which can be used to present the results observed.

The assessment was then carried out in the following three steps:

- 1) Grading the efficiency and ease of use of each computer application to perform the operations considered in Table 1;
- 2) Multiplying each of these grades by the respective factor assigned in Table 1, and
- 3) Summing the products obtained for each activity, and then normalizing the sum to a value of 100 (= case of maximum grade for all activities).

4. Results

Table 2 lists the grades given to each computer application for the single operations 1 to 10 of Table 1.

As established in the preceding section, these grades were multiplied by the respective factors from Table 1, and the resulting products were summed and then normalized to a reference value of 100 for each computer application.

Example (for Audacity and learning activity 'a'):

Obtained value:	$0.8 \times 2 + 0.9 \times 8 + + 0 \times 8$	= 19.6
Reference value:	$0.8 \times 10 + 0.9 \times 10 + \ldots + 0 \times 10$	= 31.0
Normalized value:	19.6 /	$31.0 \times 100 = 63.2$

Table 3 contains the results for every learning activity. Figure 2 shows the results in a bar graph.

In addition, appropriated weights were established for each activity according to the activity's respective estimated relevance to our course on wave physics and acoustics. And overall grade for each computer application was then calculated as the mean weighted grade. These overall grades, together with the assigned weights, are also shown in Table 3 and Figure 2.

		assigned weight	Audacity	WaveLab	Adobe A.
a)	Fund. frequency, pitch and wave form	0.20	63	82	87
b)	Fourier analysis	0.20	73	82	73
c)	Timbre, wave form and spectrum	0.12	67	80	78
d)	Timbre, growth and decay	0.10	60	83	86
e)	Amplitude and loudness	0.18	46	89	90
f)	Formation of beats	0.12	85	78	58
g)	Synthesis of timbres	0.08	86	79	51
Ove	erall grade (= weighted mean grade)		67	82	77

Table 3. Grade of each application for each learning activity considered, and overall grade for all learning activities (normalized to an ideal maximum value of 100).



Figure 2. Bar graph of the results in Table 3.

5. Discussion

Certainly, our results are based on estimates. Nevertheless, as these estimates are based on our experience from the teaching practice, they should not differ greatly from any theoretically more objective values as far as efficiency and ease of use are concerned. Thus we can conclude, for example, that Adobe Audition is clearly the most suitable application for activity a), whereas WaveLab is the most suitable for activity b), and Audacity is the best for activities f) and g).

These examples illustrate also that the overall grade has to be seen as a guiding value, and not as a statement of "the winner", since the decision about which computer application would be the most suitable in every day's practice depends on the particular activity planned.

However, there remains one important factor which has not been taken into account because of its non-pedagogical nature, but which is highly relevant to academia: cost. The most economical application is Audacity, since it is free and available through the Internet. WaveLab from Steinberg has a release, WaveLab Essential, based on WaveLab 4, at a price of US\$150. The latest release, WaveLab 6.0, costs US\$700, but it has an educational release priced at US\$275. Adobe Audition 2.0 costs US\$349. A special educational release is also offered, but we could not find the price. The fact that Audacity is free and has sufficient features makes it very attractive for implementing learning activities for many students at practically no cost and with no piracy problems.

6. Conclusions

We have compared three sound processing applications as tools for a set of learning activities on wave physics and acoustics. One of them, WaveLab could be considered as a sort of "winner" because of its highest overall grade. Nevertheless, each one of the other applications, Adobe Audition and Audacity, scored highest for at least one of the learning activities considered, i.e., the choice of the computer application depends on which learning activity has to be implemented.

In order to come to these results, we have developed an assessment procedure which can be also used for other sound processors or/and learning activities.

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Laboratory Activities in Physics Education

A Learning Model (MATLaF) for Conceptual Development in Laboratory: Mechanical Waves

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Abstract

In laboratory work, the theoretical and the methodological domain are interrelated. Our research, grounded in Vergnaud's theory of conceptual fields, is concerned with modeling this process through the use of a dynamic learning model (MATLaF). We describe conceptual developments in the theoretical domain of students performing laboratory work on the subject of mechanical waves, guided by the MATLaF model. The study involves students studying to become physics teachers on the Laboratory III course at UPEL-IPC, a university in Venezuela. The data collection process was carried out in three stages. Firstly, students were given three questionnaires and they all participated in one collective interview. Having completed a set of guided simulations (applets), relevant information was extracted from their conclusions. Finally, their laboratory reports and questionnaires were subjected to rigorous analysis. The results showed that the initial conceptual model held by the students developed satisfactorily in relation to both the complexity of their scientific ideas and their approach to scientific concepts involved in laboratory work. *Keywords*. Conceptual development, laboratory work, mechanical wave

Introduction

In laboratory work, the learning in the methodological domain predominates and, furthermore, that it is inseparably interrelated with a theoretical frame of reference associated with a given situation (Hodson, 1984, Duit, 1995, Serè, 2002). Therefore, it may be said that students are constantly reworking their theoretical-methodological concepts during the resolution of Laboratory Work (LW).

The cognitive dynamic in LW is a complex one. In order to understand it further and to be able to orient teaching,

we have designed a model (MATLaF) (Andrés, 2005) that allows the cognitive processes during LW to be

analyzed, which is based on the theory of conceptual fields (TCF) (Vergnaud, 1990) and, which, also, guides the

didactic actions (Andrés and others, in press)

The TCF proposes that the subject learns in action, in the face of situations that are confronted by activating *schemes*. These cognitive structures are constituted by:

- i) *Operational invariants (OI)*: (concepts-in-action, CiA, and theorems-in-action, TiA) the properties of the concepts activated in the face of the situation, which are used for the identification and selection of the information, the production of inferences and the selection of the rules of action that will be applied. This component is of greatest interest for researchers, as it contains an explicit element that is upheld by another implicit one, on the basis of which the subject acts (Vergnaud, 1990; 1998).
- ii) *Goals and expectations:* that identify the situation as characteristic of a set.
- iii) *Rules of action* that are usually of the type "if.... then"; from which a sequence of specific actions are generated for the situation.
- iv) *Possibilities for inference*: reasoning that allows an evaluation, in the "here and now", of the rules and expectations on the basis of the operational invariants activated by the subject.

In the TCF, it is thought that the concepts are formed of three sets (figure 1):



construction of new schemes is the result of placing students in novel situations, in which they combine elements of various schemes, and construct new conceptions that will progressively lead to the mastery of new set of situations. The TCF proposes that conceptual development is a progressive process.

The situations are constituted by complex tasks (a combination of sub-tasks) the difficulty of which depends more on the conceptualization required to approach them than on the quantity of sub-tasks. In each situation, some properties (OI) of the concepts are applied, providing the latter with meaning. They may be grouped into different set, according to the nature of the concepts Figure 2. Plan of action for the development of the Laboratory Work. Interrelated between theoretical and the methodological domains.





required for their solution.

If LW begins with a problem-situation, it will be necessary to activate very different schemes given the conceptual complexity of the sub-tasks (figure 2)

In the MATLaF model (figure 3), LW begins with a novel problem-situation, mental models⁸ (MM) are repeatedly developed until an action plan is established. An MM is a transitory cognitive structure: however. it would seem that during its development stable elements of the OI-type

remain in place, which we can consider as the precursors of the concepts under construction. Analysis of the problem implies activating some kind of theoretical reference and establishing physical models in order to

⁸ We understand Mental Models in the sense given by Johnson-Laird

approach it, through which the situation is reformulated and relevant questions are raised for the actual experimental work (Phase I, figure 2).

This first step imposes new goals and deals with one sequence of sub-tasks (Phases II to V, figure 2), which may be either known or new; in this case, solutions for each one will involve cognitive cycles similar to the initial one (figure 3)

Questions

Whether the LW is centered on the solution of problem-situations relating to the nature of the waves, the propagation of the waves and the dependence of wave velocity on other variables, that is guided by the MATLaF model (figure 3), and oriented towards interplay between theoretical and methodological aspects (figure 2), it will facilitate students' conceptual development in the *theoretical, methodological* and *epistemological* domains.

In the theoretical domain, the learning (conceptual development) is identifiable for the progress that the students exhibit in the IO with which confront the situations of the same set.

Research design and methodology

A qualitative study of cases it was carried out with five

(5) students⁹; three (3) male and (2) female. They had between 20 and 26 years of age. Who had previously passed two conventional laboratory courses, (mechanics, electromagnetism) where they didn't take decisions about the design and the emphasis was in the gathering and transformation of data.

The test lasted four weeks (five hours/week). The data collection process was carried out in three stages (table 1)

Figure 4. Window of the simulation "Propagation of harmonics longitudinal waves along the bar, produced by a vibratory source with simple harmonic move", for confronting the ideas relatives to: vibration of each point of the medium and travel of the wave when he goes by. This simulation allows varying the speed of pulse and the wavelength, and it calculates the frequency, the period and the lapsed time in automatic form. In the simulation there are two types of simultaneous representations: the pictorial (particles distributed along the bar)

and the symbolic (graph of the function of wave in the time) (www.sc.ehu.es/sbwch/fisica/ondas/ondaArmónica/ondasArmónicas.html)



Table 1. St	age of study	and form	of gathering data
ass	ociated with	the activit	ty in LW.

	Data collection	Activity in LW
Stage of study		
Initial, E _o	Questionnaires and one collective interview	Phase I
Intermediate, E _i	Conclusions of the students, post simulation (applets)	Between Phase I and II
Final part I, E _{F1}	Laboratory Report	Phase II to V

Phase I

It began with the presentation of a group of situations referring to mechanical waves: the nature of the waves, wave propagation and the dependence of wave velocitv on other variables, (example in annex) to which they had to respond individually and in writing. In the following class. а collective discussion was held on the subject of each student's answers, where they had to argue and defend their proposals; the teacher intervened to encourage participation and discussion among all of

the students. The session drew to a close with the group establishing a set of relevant questions for experimental work and hypotheses based on concepts and conceptual relations. The individual written replies and the audio recording of the collective discussion were analyzed in order to identify the initial models and meanings used by the students (CiA and TiA)

⁹ Laboratory course for students studying to become physics teachers at university UPEL-IPC (Venezuela)

Simulation. This activated the signified meanings (OI) identified at the outset as inconsistent from the scientific perspective. Each simulation was accompanied by a script for interaction based on questions; that requested the students that make predictions about what it would occur; then they interacted with the simulation and they compared their observations with their answers. Finally, the students had to set out their conclusions on what was analyzed in the simulation in writing. These conclusions were taken as an intermediate stage of the signified meanings (OI) of the students

The lecturer-investigator observed the groups of work and mediated with questions, orientations, lectures and others. Upon concluding each phase, the work carried out was discussed in collective.

Phase II

The students designed the plan to execute the phases II and IV of the LW. A set of experiments on pulse propagation in springs where they varied the conditions:

i) Of the medium (tension and lineal density)

ii) Of the source (form of the pulse and speed of the movement of the hand), in order to study their effect on the speed of propagation of the pulse. They took videos of each experiment.

Phase III

Measurements were made on videos. They collected data about position, amplitude and pulse length traveling along the spring, using VideoPoint^{TM10} software (Figure 5). Having completed the LW, the students drew up a laboratory report, guided by an action plan (figure 2). In addition, they also completed a questionnaire (example in

annex), equivalent to the initial one, with two situations of the same set.

Results

The results are laid out in stages: initial, intermediate (after the simulation) and final results, in order to analyze the conceptual evolution (table 2, annex).

Initial stage. The association of the speed of wave with the frequency of the generating source and the properties of the medium is seen to predominate. Two students considered that it was feasible to change the speed of wave, *when vibrations are produced with greater force*; the arguments given for this TiA are based on Newton's Second Law, in the pulse-particle model.

These results are similar to those found by Wittmann (1998), who summarized the

Figure 5. Peak position of a pulse propagating along the spring, as a function of time. Experimental result for the speed of pulse is (9.2 ± 0.3) m/s, for a tension of (13.22 ± 0.02) N, a mass of (0.663 ± 0.001) kg and a length of (4.438)



different models of the students in: the Newtonian model of the particle, the pulse-particle model and the wave model. Similarly, Bravo and Pesa (2002, 2004) reported that the students faced with similar situations from the scientific perspective, activate different schemes that present meanings and representations approximating in different degrees to those accepted in physics.

In view of the signified meanings in the *theoretical* domain that are inconsistent with scientific knowledge, three learning outcomes were proposed for the LW:

i) Role of the propagation medium in determining the speed of wave.

ii) Independence between the characteristics of the vibration of the source and the speed of wave.

iii) Notion of the wave as an event and not a material object that interacts with the medium.

Intermediate stage. The data showed an evolution of the students' OI (Juan and Leo); who, also, constructed a new TiA akin to scientific knowledge (Category L, table 2)

Hilda, managed to evolve in terms of differentiating between the behavior of the particles in the medium and the pulse or the wave, when propagated through the medium (category H). However, her answers in relation to the frequency, speed and wavelength, were of the textbook type and lacked supporting arguments, for which they were coded as a new category G. Yoli continued showing hybrid reasoning (Categories: A, H, J). And, Carlos, was unable to resolve the proposed task in the simulations.

¹⁰ VideoPointTM (v.2.5) Lenox Software Lenox, MA.01240, 2001, licence held by Maite Andrés.

Final stage I. (Laboratory Report) Five aspects of the contents of the laboratory reports were analyzed (Phases, figure 2). For the purposes of conceptual development referring to the theoretical domain associated with the theme of the mechanical waves, only the results of the *conceptual analysis* and *conclusions* were considered.

Final stage II, (Final Situations). They use a smaller range of OI for its solution. Four students used the category L and L₁'. And, Yoli worked with multiple interdependent variables, this is a evidence of their understanding of the meaning of the relation λ : g(v,f) accepted in the scientific community. In addition, three of the students used two forms of representation: linguistic and mathematical symbols.

In summary, the table 2 shows that three students strengthened the OI relating to the dependence between the propagation velocity of the pulse and the properties of the medium (categories L and L_1); and all discounted for these situations the OIs that associate the propagation velocity of the pulse with the frequency of the source (category J).

Conclusions and implications

Understanding the cognitive process at work in the approach to the sub-tasks of the LW with the MATLaF model helped orient students in their conceptual development. Also, he was appropriated for identifying the conceptual development of students in relation to the proposed situation in the different phases.

According to the results, in this study conscious construction and reconstruction by the students of the signified meanings of the model in order to resolve the situation were greatly stimulated.

The achievements were not uniform (two showed intermediate evolution), which shows that learning is individual, progressive and not linear and that it requires the solution of multiple situations of the same class before they can be mastered, which is to say, before cognitive schemes can be constructed that are appropriate for their solution.

This progress in the theoretical domain is not independent, we also observed advanced in the methodological and epistemological domains (Andrés, 2005)

From an epistemological perspective, it is important that the LW is developed as an activity in which there is an inseparable interrelation between the theoretical and the methodological domains. Although the main emphasis is on the latter domain, it is not possible to decouple it from the theoretical model associated with the situation that is presented.

It would appear that this conception of LW guided by the MATLaF cognitive analysis enables significant longterm changes to be achieved in the conceptual development of the students in relation to the theoretical domain together with the methodological domain, which contribute, in turn, to the development of an increasingly scientific vision of the experimental activity.

This potential ability of MATLaF has important implications for planning teaching in the laboratory.

- 1. Identifying the level of conceptual development and the difficulties experienced by students in the theoretical domain that is associated with the proposed situation is extremely relevant when setting the learning outcomes for subsequent LW and selecting situations. This, in turn, facilitates the evaluation of their effectiveness; an aspect that has been reported elsewhere as a requirement (Séré, 2002).
- 2. In addition, it is also relevant in establishing sequences of situations for laboratory courses, while paying attention to a conceptual hierarchy within the methodological domain, and grounded in theoretical domains that facilitate an understanding of meanings that are relevant in physics education, which are problematic for learners.

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Proposed situation II.1 and II.2 of INITIAL QUESTIONNAIRE: Mechanical Waves. Aspects on the theme: II.1. A long rope that is tensed and attached to wall some distance away Somebody's hand moves up and down in a time thand, creating a pulse of small amplitude that reaches the wall in a time t_o (see diagram). A small red point is painted midway on the rope, between the person's hand and the wall. ~ When the pulse moves past the red point, how does this part of the rope move? Explain Punto rojo How long does the movement of the red point last? Explain II.2. A particle of dust is positioned in front of a silent loudspeaker (see figure). The loudspeaker is turned on and emits a note at a constant frequency. Describe the movement of the particle of dust. Explain your reasoning. (Wave Diagnostic Test, UMd, Wittmann, Steinberg and Redish, 2001) Partícula de polvo Altavoz

Situation A. FINAL QUESTIONNAIRE: Mechanical Waves

Aspects on the theme. The nature of waves: Relation between the propagation velocity and frequency of the source and properties of the medium

A) Two large, identical ropes are held at equal tension on the floor. Two people send a pulse, each of them along one rope. In a length of time "t" the ropes are photographed, and movements are observed as in the figure:

Which of the following statements appear to you to be correct? Justify your answers.

- 1. The propagation velocity of the pulse in rope 2 is greater than in the rope
- 2. Pulse 2 was sent before pulse 1.

(1) (2) (The pulse travels towards the right \rightarrow)

Models of students: Theorem-en-action	Leo		Hilda			Yoli			Carlos			Juan								
Consistent with accepted scientific meanings	Eo	Ei	$\mathbf{E}_{\mathbf{F1}}$	E _{F2}	Eo	Ei	$\mathbf{E}_{\mathbf{F1}}$	E _{F2}	Eo	Ei	$\mathbf{E}_{\mathbf{F1}}$	E _{F2}	Eo	E_i	E_{F1}	E_{F2}	Eo	E_i	E_{F1}	E_{F2}
А.	Х	Х	Х		Х	Х	Х			Х	Х			Χ	Х		Х	Χ	Х	
В	Х																			
E.	Х				Х				Х				Х				Х			
F.																	Х			
L.		Х																Χ		
$L_1 ilde{O}$			Х	Х							Х					Х			Х	Х
$L_2 \tilde{O}$												Х								
Inconsistent with accepted scientific meanings																				
D.	Х																			
Н.										Х										
I.																	Х			
J.	Х				Х				Х	Х			Х				Χ			
К.													Х							
G.		Х			Х	Х	Х	Х								Χ	Χ			

Table 2. Conceptual evolution of the students (Leo, Hilda, Yoli, Carlos and Juan) in the theoretical domain during the development of LW about waves in springs (States: initial E_0 : intermediate E_i : final 1: Final Report E_{E_1} : final 2: Final Ouestionnaire E_{E_2}).

Models of students: Theorem-en-action

- A. The wave transports energy
- A. The medium itself is not transport for the wave
- A. The particles in a material media where it is propagating a pulse, are not independents, interacting to each other
- B The figures similar to the sinusoidal representation employed for the wave constitute un perceptual effect that is not relevant in order to decide on a scientific bases whether one situation put forward involves a wave.
- E. If a source generates the disturbance (motorboat, vibration of the vocal cords, hand) and it is "connecting" to a medium, then a wave is traveling along this.
- E. Sound is traveling as longitudinal wave in the elastic medium.
- F. A sinusoidal figure is only pictorially similar to a wave. The representation of the sin or cosine function for a simply harmonic motion is similar to the representation of a wave. The shape is not a scientific criteria to consider that something is or is not a wave
- L. The speed of wave depends on the medium in which it is propagated
- L_1 . If the strings are identical they have equal lineal density. If the Tension (T) of the strings is the same and so is their lineal density (ρ), the propagation velocity (v) of the pulses that travel along them will be of equal speed, because: $v = (T/\rho)^{1/2}$
- L_2 Working with multiple interdependent variables, which influence their understanding of the meaning of the relation λ : g(v, t)

D. The particles of the medium oscillates without considering the existence of bonds between them

H. The particle of the medium oscillates with a speed that is equal to the speed of pulse that is propagated through this.

I. The wave has a quantity of movement (p=mv) I. The wave collides with the particles of the medium I. The wave is a material object.

J. The wave velocity depends on its frequency. J. The characteristics of the movement of the source (frequency, amplitude, energy, force) determine the characteristics of the particle oscillation in the medium wherever the disturbance is propagated and of the wave. J. The wavelength depends on its amplitude.

 758^{J} . The speed of wave depends on its amplitude. K. The waves meet and are absorbed by each other J. If the amplitude of sound changes, then its speed varies

E - Evaluating scholar performances. Between theory and practice

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Abstract

The students who are preparing for an internal or an external evaluation need practice and a coach. Practice can be assured by specialized educational software, which evaluates competences and the coach can be the computer. The designed program is a flexible one which takes in consideration the evaluating process, the way it is taking place every day in the Romanian learning institutions.

Evaluation centered on competences

The students who prepare for a school contest, national exam or an admission contest need a message which can certify the skills they have. Physics is a school discipline which could easily quantize student's performances [1]. Checking the level of the students is made in most of the cases by solving theoretical problems.

"To know how to apply in practice" was interpreted for a long time by the Physics teacher as "solving theoretical problems". The problems were most of the time formulated in an abstract way, "hard to be digested" by the students, whose interest was obviously failing [2].

With the finance of Romanian National Council of Research (CNCSIS) in Iasi district and some of the nearby districts the project "Harmonizing evaluating systems" is going on, from current evaluation, to the one through national and international physics school contests [3]. The purpose of the project is to feel out the evaluating system of scholar performances. It is taking place in 35 schools from different regions of Romania, with different school averages and students. The teachers involved in the project have elaborated tests centered on competences. Groups of students with different levels of performances were tested. The tests were calibrated with the help of performances descriptors, recommended by the National Council of Evaluation for Middle and High School. Through the evaluated students there are also included, students with regular school performances but also students with remarkable performances who develop activities in Centers for Excellence. The pedagogical research followed to obtain a feedback, which will allow identifying student's individual needs. This evaluation serves also for noticing the performances reached by the students who are having problems with representing concepts [4]. Identifying the systematic mistakes, made by the students in solving the items give to the teachers the possibility to improve the teaching methods. Iterating the evaluation process students can prepare national contests and the Baccalaureate. Research has also surveyed the performances progress of the students acting in Centers for Excellence in order to elaborate models for students learning. These should help brilliant children to represent with precision basic physics concepts and apply them in solving problems.

Elaborating educational software of on-line evaluation was one of the sub adjacent objectives of the project. The computer program wishes to assure an evaluation tool for the students and teachers interested in the quality learning process. Students need auto evaluation and the one offered by the computer has very many advantages. The computer is a discreet evaluator and can assure a feed-back with direct referrals at the informational resources. These can improve the way of physics learning and assure the transition to a superior level of performance.

In elaborating the tests, the level of operational objectives was taken into consideration. In the instructional activity the teacher transposes the purposes of education in terms of mental, psychomotor and attitudinal skills. The evaluating test, conceived by the project's team, tried

to clarify the retention and recognition processes of the basic physics conceptions. It was tested the ability of the student to operate with physical concepts and to operate with physics lows and physics principles. The ability of the students to imagine and reproduce the interdependence relation between phenomena was also tested. The items were centered on competences of the students to solve theoretical and practical problems.

In the undertaken pedagogical research, there were some principles to be respected: the principle pf the behavioral hierarchy, the principle of the discriminating performances, the principle of the internal consistence. In the first stage the research took place in 6 high schools from Iasi, members of the Centre of Excellence. The results and the levels of preparation which students had were compared, taking in to account the particularities of each group of students. Talking with the teachers and explaining the differences were identified the didactic strategies which could lead to a better understanding of the concepts by the students. In order to be successful, students must be prepared in the spirit of the exams they are going to sustain. As a consequence, all along the research during high school years, will be surveyed the harmonization between the scholar competences and the objectives recommended by the Baccalaureate exam, with the aim of preparing the students in the spirit of these national contest.

Computer assisted evaluation

The Physics teachers have agreed from the beginning the use of the computer in their professional development and in students computer assisted instruction. The computer can be an instrument of assisted learning but also a very efficient and precise performance assessment tool. Using computer software different phenomena can be simulated. The physics laboratory can also go behind the screen and we can resort to it as "virtual".

There are many attempts to plan and realize e-evaluation of student groups and even for school contests administrated by the computer [5]. Taking these experiences into account it began, in the frame of this project, the designing of software which would use data bases realized by the teachers involved in the project. The program is destined to both junior high schools and high school students. It can also be used by the students which prepare their selves for sustaining the Baccalaureate exam but also for the university candidates who are going to sustain an exam in Physics subject.

The program is designed to generate Multiple Choice physics tests, with different structures and of different complexities, from an existent data base which covers the main chapter of Physics.

The characteristics of the program

The program has many facilities:

- It is easy to install, no special computer knowledge is needed;
- Does not need any special hardware resources, allowing it to work on different platforms (Windows 98, Windows Millennium, Windows 2000, Windows XP);

- It is quickly produced a very high number of assessment tests, from one, two, or more chapters;

- Performance assessment is quickly and objective;

- The program can be used in learning and training for national and international contests. The immediate correction during the assisted test allows a quick and efficient feedback;

- Offers an interactive help;

- The existence of a large number of testing options. The program covers a large area of test models being able to be used at the end of a chapter for final assessment, for pre-testing the Baccalaureate exam or training the admission exam at a university.

Using the program presents the following advantages:

- Represents a form of evaluation centred on competences;
- The auto evaluation of the performances is individualized;
- The process of identifying the level of competence is very fast;
- The attractive interface stimulates student's interest;

- Contains a very large database (over 2000 items);

- It can be used in a Intranet, because every candidate has his own version (the tests are randomly generated);

- The numbered registration of the tests allows the teacher to follow the student's progress from the school.

By creating, testing and using this software, designed to evaluate students performance, we hope to realize a way and a strategy of modern evaluation which will not only be in the benefit oh students, who can now check and perfect their knowledge in Physics, but also in the benefit of the teachers who can use the informatics laboratory in order to evaluate interactively the students skills.

The program was created in Visual Basic 6 language. The whole concept belongs to the author [6]. The items included in the tests were elaborated after consulting many references and textbooks and Physics curricula for the Baccalaureate exam, elaborated by the Romanian Ministry of Education, by a large collective of teachers [7].

The software does not try to replace the classic methods of assessment but only to enrich the palette of used instruments. It offers to the Physics teachers an additional instrument to asses the skills of the students in solving Physics questions. The program can be integrated step by step in the process of examining students.

In realizing it, it was taken in consideration how well are the schools in Romania equipped, and how well prepared the teachers are in using informatics technologies.

Installing and using the program

The program is easy to install on the computer through a double click on Setup.exe from the installing kit, followed by the specification where will the directory be placed. The application is launched like any other program that opens on platforms WINDOWS 98/ME/2000/XP, following START ->PROGRAME -> TestFiz or by creating a quick command.



Fig. 1 First screen.

Fig. 2 The test is under the way

Installing the software and generating test

The application contains more windows you can navigate on:

-First window (see Figure 1) allows the optional insertion of data information about the candidate and the possibility of choosing a method of work. After this, another window is opened depending on the type of the test he or she has:

- o Baccalaureate test ;
- Test dealing with a specific chapter;
- Test similar to the university admission contest;
- o Assisted test for learning.

In this program there is also a couple of general information about the program. For example, the Baccalaureate test window (see figure 2), determines the candidate to pick two theme areas (from four possible: mechanics, electricity, thermodynamics, and optics). After this a

version of a test will be generated. The items appear once with pressing the button with the number of the question and the answer is being introduced in the adjacent box. The program contains a database with problems from which 30 items (15 from each area from the two chosen ones) are chosen on the base of an established algorithm. The time left for working appears permanently and when the time is off, or at the command of the user, the program shows the obtained results and the points scored. The results of the test with the right answers can be visualized and then listed through a simple click on the "print results" button (see figure 3).





Fig. 4 Assisted Test window

The windows containing the tests on different Physics chapters or the university tests, work in a similar way, the only differences are the way of generating the test, the score calculation and the graphic aspect of the interface.

The basic instructions about using the program can be accessed from any window by pressing the "help" button.

The Assisted Test window (see figure 4) allows the user to resolve in a period of unlimited time a version of a test from a chapter, generated by the computer. The right answer version is immediately posted allowing the candidate to learn quickly. The evaluation can be made in any moment.

Conclusions

The program will be developed after being applied for a year in the schools involved in the project. The feedback given by the teachers and the students will help developing this project.

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Measurement-Based School Physics Experiments With Everyday Objects

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Abstract

The classroom demonstrations where normally the measurements are absent sometimes make the students relatively passive observers. Physics teaching in schools can actually be supplemented by simple experiments involving measurements even if these are not the part of the curriculum. In the developing countries that includes India a wide range of inexpensive but useful materials are now available for designing these simple experiments. With some inexpensive measuring instruments one can carry out meaningful measurements in a large number of physics experiments designed mostly with the everyday objects. The whole exercise demands different types of skill form a learner. With some guidance from the teachers the process becomes a participatory one involving a two-way communication. Most of these experiments can actually be done outside a conventional laboratory. However, one should not expect very accurate results with the rudimentary measuring equipment. Rather the whole exercise should be treated as a part of the learning process for both theory and experiment.

Introduction

Students enter the undergraduate (UG) classes after 12 years (10 + 2) of schooling in India. This is a vast country with regional and cultural variations that leads to the variation of different aspects of education as well. A section of the enthusiastic teachers or the invited educators with limited resources occasionally arrange for some classroom demonstrations to make the middle school and high school science teaching interesting. This does play a significant role in making the students enthusiastic towards science but the exercise is vastly inadequate.

These efforts at the schools can actually be supplemented by simple experiments involving measurements even when these experiments are not the part of the curriculum. The exercise involves the students in hands-on activities that enhance the learning process and the role of experimentation in physics gets highlighted. In the developing countries a wide range of inexpensive but useful materials and equipment are now available for designing these simple experiments and carrying out some rudimentary measurements. Through measurements the students can verify certain physical principles and laws and can measure some physical properties of the materials and meaningful results can be extracted through the analysis of the data and subsequent calculations. The whole exercise demands different types of skills form a learner. With a little guidance from the teachers the process becomes participatory involving a two-way communication. Since most of the experiments can be done outside a conventional laboratory, say in a classroom, there is not much of a problem in organizing the exercise.

Scenario of the laboratory component of the science education in schools in India

In India there are more than 25 Boards that administer the final school level examinations in different parts of the country. But only a handful of Boards involving not a very large number of students offer practical in grades 9 and 10. Laboratory component in physics and in other science subjects come in a big way at the level they enter after the first ten years of schooling in India. This level, popularly known as "plus two" level, and comprises of grades 11 and 12 puts up the students under tremendous academic stress in a short span of time. This is particularly so because the entrance tests the students

take the end of this stage for entering some very reputed premiere academic institutes mostly imparting education in engineering and medicine do not have a practical component. In the process the laboratory work remains neglected.

The students' attitude towards experiments actually stems from the attitude of the guardians, teachers and from that of the society. So the practical training remains a neglected component even being the part of the curriculum. It is being felt, if the students at the middle school are exposed to do some simple measurements that may orient them towards formal experiments in a more effective way when they come across them in the curriculum. Particularly quite a significant number of experiments can not only be designed with the everyday objects but for the associated act of measurement and the generation of data one may not need a formal laboratory. The classroom, the ground outside or even students' home are good enough for this exercise to conduct even when it is not the part of the curriculum.

Orienting the students at the middle school for laboratory experiments: The methodology

Middle school students need to be oriented for experiments involving measurements though some steps that are known by the names like guesstimation, order of magnitude calculations, calibration experiment and activities apart from the usual experiments for the measurements of physical quantities and the verification of physical laws and principles. It has been observed that a middle school student at her early teens take keen interest in the experiments as she can correlate the materials form the text books with the real world. It is up to a teacher to judge the level at which one particular experiment may be introduced to the students. A brief outline about the types of hands-on work is given below.

(i) Guesstimation:

This is a word that has been coined by combining two well-known words viz. 'guess' and 'estimation'. This is something we actually do in our social life. For example we try to guess the height of a person by looking at him, we try to gauge whether one is having a fever or not by touching his body, we try to estimate the speed of a train by looking at the marked posts by the side of the railway track and using our watch etc. Similarly the students may be asked to estimate the mass of air in a room while the approximate density of air at that temperature will be supplied. Students try to estimate different dimensions of the room, calculate the volume of the room and then the mass of the air present. And to their surprise they quite often discover that the air is the single heaviest material in the room. There are quite a few of other estimations of this type that can be tried out.

ii) Order of magnitude calculations:

The order of magnitude calculations help the students to get familiarize with the largeness or smallness of a particular quantity. This helps the learning and handling of units of physical quantities. A significant number of students entering the undergraduate class after the 12th grade do not have the desired level of command over units. Though they are familiar with the names of the units but lack in the concept of their real life sizes.

iii) Measurement of some physical quantities and verification of some physical principles:

These may be referred to as the standard conventional experiments. However the most of these experiments can be designed with the everyday objects and the corresponding measurements can be carried out with inexpensive equipment though the accuracy may not be of very high degree. For example, a single light uniform stick (about 50-60 cm length) of wood or light metal like aluminum may be used for the comparison of masses and the measurement of specific gravity. A vernier scale

with vernier constant 0.1 cm may be constructed to understand the role of vernier. A suggestive list of such experiments has been given in the appendix.

iv) Calibration experiments:

Calibration of different measuring tools is another concept that should be kept before the students. Take, for example, the case of the calibration of a spring that can be used for the measurement of weights. A spring needs to be calibrated with a few known weights. And by checking the linear behaviour of the weight vs. extension graph of a spring within the specific range one can employ the spring as a device for measuring weights. Students may be given properly chosen empty mineral water bottles made of transparent plastic with a uniform cylindrical cross section at least in the middle and be asked to make a properly calibrated measuring cylinder. Construction of a vernier scale of vernier constants 0.1cm (least count 1 cm and 10 vernier divisions are equal to 9 main scale division) or 0.05cm may be taken up as exercises for the students of high school. They can verify or can check back what they have measured with a metre scale with 1 mm least count.

v) Activities involving the teamwork and fieldwork:

Large number of activities involving some rudimentary measurements and calculations may be undertaken inside as well as outside the classroom. These are essentially group work and these demand a special type of attitude from the learners. They need to work in relatively big teams for conducting fieldwork. The importance of physics in real life problem solving can actually be highlighted through these types of activities. These activities may include the measurement of a big ground dividing it into different well known geometrical areas, calculation of the speed of walking of different students, tossing up of a coin for 100 times to check the nature of outcomes etc.

Handling the different aspects of the measurement-based experiments

As such the experiments included in the curriculum of the plus two level (grades 11 and 12) in India are well spread out over the syllabus and are well-known conventional experiments. For the middle school students one needs to plan measurement-based experiments in the classroom or in the science corner of the schools and can think of designing the standard experiments in a slightly different way to achieve the objective. One may need to replace a few conventional equipment or experimental set ups with those designed with everyday objects and the number of set ups can be multiplied without much expense.

While performing the measurement-based experiments numbers of different types of skill are expected from the learners as these involve a number of steps that may be listed as

- (i) Observation of the phenomenon that concerns an experiment and planning of the work.
- (ii) Careful conduction of measurement with the help of the equipment provided.
- (iii) Collection of raw data obtained through measurement.
- (iv) Analysis of the data collected and repetition of some parts if necessary. In most of the experiments either some physical quantities are measured or some physical principles or laws are verified and the students are expected to have some idea about the trend of the data and may be guided that way. However, this should not make them biased.
- (v) Calculation of the results from the collected data and its comparison with the standard results.
- (vi) Drawing of suitable graphs wherever possible. This of course needs some training and may be started with the students of relatively higher grades like grades 9 and 10.

It has been observed that a student is not equally comfortable in all the sections of the work mentioned above. Some are good in handling the apparatus; some are efficient in calculations while some others may apply better judgment in the collection of data. It becomes the teachers' task and definitely not an easy one, to identify the students' ability or shortcoming in different types of skills and to guide them accordingly for the enhancement of a particular skill. The analysis of error has deliberately been left out of the ambit of this discussion, as we really cannot introduce the concept before the UG level.

Discussion

This paper deals with the Indian context and India is essentially a developing country. However, there are certain common features of the students that may be global in nature as far as the laboratory work is concerned. These include lack of confidence in the units, application of proper judgment in collection of data and drawing graphs, 'experiments don't work' type attitude etc. that persists well in the UG level. Lack of interest in the concepts like error analysis, significant figure, accuracy, precision etc is also widely observed in the UG classes. All these lead to a situation where the teachers find that the students are asking only about the 'hows' of the experiments i.e. they want to know how to do it, generate some data and come out with an acceptable result. Most of the students do not ask about the 'whys' of the experiments i.e. they do not feel like asking why a particular step is taken or why a specific procedure is followed in the experiment they are asked to do.

That in a way makes them mechanical in their laboratory work. It has been observed that with some initiation in experiments where the students can apply their hands and minds together right at a tender age make a lasting imprint in their learning. They get the opportunity of asking relevant questions. With some elementary training of simple measurements at the middle school these students get involved with the experiments and feel inspired to design or improve upon the simple experiments they have dealt with. In the developing countries with limited resources this training in measurements helps the teachers to motivate the students. A section of teachers also show interest in innovations and they have been observed to contribute to this effort as well. This may help in designing more experiments including what are known as open-ended experiments and the exercise becomes more intensive. Some well-planned teachers' workshop, however, may be needed for orienting larger section of teachers in this work of conducting measurement-based experiments.

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Appendix

A List of Selected Measurement-Based School Physics Experiments and Activities with Everyday Objects

School physics experiments using everyday objects may be broadly divided in two categories viz; measurement-based laboratory experiments (M) and activities (A). The first type of work, however, can be easily done even in a classroom. And the second type of task may not demand very precise measurements but involves some sort of fieldwork, teamwork and skill. This list is just a suggestive one and more experiments can be included in the list depending on the availability of the materials and inexpensive measuring equipment.

Determination of the speed of walking by measurement of time and distance. (A)

Calculation and experimental verification of the number of revolutions of a cycle wheel in covering a distance of one km and its comparison with the theoretically calculated value. (A)

Determination the relationships between inch and cm, sq inch & sq cm, cubic inch & cubic cm. (M)

Finding the ratio of circumference and diameter in circles of different size. (M), [Measurement of circumference will involve different techniques.]

Finding the coefficients of static friction with a friction table (A, M)

Estimating the number of grains in one kilogram of granular pulses. (M)

Measurement of body temperature with a clinical thermometer. (M)

Measurement of temperature of a glassful of hot water at different time and drawing of time-temperature graph and under different conditions (i.e. with different surrounding environment). (M)

Finding the dew point. (M)

Verification of Archimedes principle with a spring balance and a graduated beaker or measuring cylinder. (M)

Verification of Newton's third law applying Archimedes' principle and using a kitchen balance and a spring balance. (M)

Determination of volume of regular shaped bodies by using metre scales & their verification using graduated beaker and applying Archimedes' principle. (M)

Study and explanation of vernier principle with a designed vernier whose VC is equal to 0.1 cm (A, M)

Construction of a spring balance and its calibration. (A, M)

Experiments for the explanation of the principles of a common balance and the turning effects and the measurement of the masses of a number of unknown bodies using a single weight. (A, M) {Next 6 experiments may be done with a uniform beam of about 50-60 cm length and mostly be measuring lengths only).

Comparison of two masses. (M)

Finding the specific gravity of some solids, heavier than water and insoluble in water (M)

Finding specific gravities of some materials lighter than water, (Using a sinker). (M)

Finding the specific gravity of a material using kerosene oil or any other suitable liquid. (M)

Finding the specific gravity of a liquid. (M)

Finding the center of mass of a weighted ruler (M)

Finding the centre of gravity of an irregular shaped laminar body. (A)

Finding height of a roof / building / tree using the principle of trigonometry or of similar triangles using laser torches. (M)

Ideas about exponential rise and fall of water level when drained out from a big PET bottle. (M)

Constructions of different classes of levers (A, M)

Extensive study of the different aspects of a simple pendulum. Finding out the factors that affect its time period. (A, M)

Construction of a simple pendulum with different types of bobs and the study of damping in their oscillations. (A, M)

Reflection of light with plane mirror and a light source (light coming through a slit, no pin for students up to class 8 and to show that angle of incidence is equal to angle of reflection. (M)

Introduction to a graph paper and explaining its utility. (A, M)

Introduction of a few simple graphs and to check the students' comprehensibility. One can try with real life graphs like mean temp vs. months of the year, petrol price vs. time, rainfall versus the dates of a month etc. (A, M)

Use of graph paper for calculation of area of a polygon. (A, M)

Drawing of graphs with laboratory generated supplied data. (A)

Determination of area of a triangle, & comparison using a graph paper and other methods. (M) [Same triangle may have different 'bases' and 'altitudes' but the area has got a unique value'.]

Construction of U-tube with polythene tube, and determination of specific gravities of liquids. (A, M)

Use of polythene U tube for the comparison of specific gravities of two liquids. (M)

Calculations of a few real life things like the mass of air present in the room, how far can a truck be loaded with bricks etc. (A)

Imparting the idea about elasticity by the study of load versus elongation of a suitably chosen rubber band. (A, M)

Study of the rotation of the reflected ray with the angle of rotation of the mirror when the incident ray remaining unchanged. (M)

Drawing the path of light rays through glass blocks and prisms and to study the refraction of light and to find out the refractive index of glass and verification of Snell's law [using laser torch as well as pins]. (M)

Construction of hollow prisms with various angles of prism and finding the refractive indices of liquids. (A, M)

Drawing of i- δ curve for a prism and finding δ_m and refractive index using pins (laser torch may be used, but with pins the generation of data is more convenient). (A, M)

Determination of focal lengths of convex and concave lenses by different methods. [There are several methods like u-v method, combination method, lens and mirror method etc.] (M)

Study of combined (convex and concave) lenses and idea about the power of a lens. (D)

Study of variation of the length of the shadow formed in the sunlight as a function of time (A, M)

Study of the outcome of combining different colours. (A, M)

Determination of focal length of spherical mirrors by different methods (M)

Measurements of resistances with multimeter and ascertaining the value of the resistances by colour code reading and their comparison. (M)

Verification of the laws of series, parallel and mixed combination of resistances. (M)

Verification of Ohm's law with carbon resistances and a multimeter and a power supply. (M)

Drawing of I-V characteristic of a semiconductor diode valve using multimeters and power supply and an introduction to the non-linear nature of the curve. (M)

Why a simple school model of AC generator does not produce sinusoidal voltage? (From false concepts to modeling and multipole expansion)

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Abstract

A simple school model with rotating bar magnet and stationary coils is often used in high schools physics lessons and labs to demonstrate the principle of an AC generator. It occurs that the time dependence of output voltage measured in a real experiment is far from students' (even university students') expectations. The article describes how results of such experiment may be discussed qualitatively at a high school level and modeled quantitatively at an introductory university level, providing also a motivation for using multipole expansion of magnetic field. Comparison with measured data shows that even a simple model is in a good agreement with experiment. The problem may thus inspire an interesting "inquiry" both at high school and university level.

1. Introduction – a simple generator, students' expectations and reality

A simple school model of AC generator consists of a rotating magnet and a coil near it - see fig. 1. When one asks undergraduate students – future physics teachers – to predict how the output voltage changes with time, it often appears that they expect:

- The output voltage to be harmonic. And, also quite often:
- The maximum voltage will be when the Fig. 1. A simple model of an AC magnet "points" to the coil (just as it is generator shown at fig. 1).

Though I did not make any statistics of similar answers, they are not rare. The problem is that they appear to be



Fig. 1. A simple model of an AC generator

misconceptions, far from truth. A real experiment with a uniformly rotating bar magnet shows that the profile of output voltage has a character like that at fig. 2 - quite surprising for someone the time. seeing for first it



Fig. 2. Typical output voltage result of a real experiment

Fig. 3. Which angle α corresponds to which part of graph at fig. 2?

Now, our problem is clearly defined: To comprehend the time dependence of the output voltage U. It appears that this problem is interesting, inspiring and solvable at various levels of understanding:

We may discuss and comprehend it qualitatively at a high school level.

- We can model it quantitatively at an (introductory) university level.
- We can even use it to illustrate an introduction of a multipole expansion.

2. Qualitative discussion at a high school level

When students are asked why the output voltage should have maximal value when a magnet "points" directly to the coil, sometimes the answer is "Because a magnetic flux is maximal". Of course, the flux is maximal (see fig. 4). However, just because it is maximal, its change is zero at this instant. (This argument can be easily explained even at high school level without using derivatives, just by drawing the graph showing how the magnetic flux changes with time.) That's why the position of the magnet shown at fig. 4 corresponds to point 0 at fig. 5.



Fig. 4. The magnetic flux has maximum

Fig. 5. Details of U(t)

The voltage is at maximum (or minimum) when the flux changes most rapidly. Maximal increase of the flux occurs at the position of the magnet shown at fig. 6. We can conclude that this position corresponds to point 1 at fig. 5. Similarly, the position at fig. 7 corresponds to point 2 at fig. 5.



Fig. 6.

Fig. 7.

Now we can say we understand the shape of the graph qualitatively. We know why there is a negative peak there closely followed by a positive one. In the same way we may discuss why the voltage is lower between two positive peaks and explain it by a slower change of the flux. We may even conclude that the peaks will be narrower if the coil is closer to the magnet (and the coil is sufficiently small) and try to estimate the values of the voltage, at least to the order of magnitude. But let us rather look at some quantitative modeling.

3. Field of a bar magnet modeled by a field of a finite dipole

To compute the output voltage theoretically, we must start with some model of the field of a bar magnet. We will simply model our magnet by a (non-elementary) dipole, i.e. by a pair of magnetic charges +Q and -Q at the poles of the magnet – see fig. 8. Such model may seem to be too rough but it appeared to give surprisingly good results. And it enables to compute the field quite easily, using the analogy with formulas from electrostatics. (Of course, we should remind to students that in reality there are no magnetic monopoles at the end points of the magnet – a good opportunity to comment the difference between models and reality; however we are not going to discuss these issues in this article.)



Fig. 8. Model of a bar magnet - two magnetic charges

It is sufficient to compute just the component Bx, which is, in fact, the radial component Br of the magnetic induction. It is an elementary exercise at introductory university level to compute it, so instead of writing the resulting formula, we directly come to the results. These are summarized at figure 9.



Fig. 9. Radial component of magnetic induction (in mT) as function of angle α for several distances r – a comparison of the theoretical model (solid line) and the measurements (squares)

The magnet used in the experiment was 13 cm long and the 1 cm wide. The value of the magnetic charge Q was set by trial and error to fit the experimental results. Some more details may be found at web version [1] of this article.

4. Modeling of the voltage in the coil

To compute the magnetic flux Φ and its changes we will use a simple "2-D model". By this we mean that we will compute the magnetic field just in the plane shown at fig. 8. Then, while calculating the flux Φ , we will just multiply the induction by the perpendicular dimension of the coil, say b. (As to the other dimension of the coil, see the derivation below.) We also assume that the coil is flat, so that all its turns are at the same distance r from the

centre of the magnet – see fig. 10.

The "vertical" width of the coil, $2r \cdot \sin(\theta_0)$ needn't be small. The magnetic flux through the coil is

$$\Phi = \int_{-\theta_0}^{\theta_0} B_r \cdot b \cdot r \cdot d\theta$$

Denoting $B_r(\alpha)$ the radial component of Fig. 10. magnetic induction in the centre of the coil when the magnet is rotated by the angle α as we used it in fig. 8 and in graphs in fig. 9, we may write the formula for Φ as

$$\Phi = \int_{-\theta_0}^{\theta_0} B_r(\alpha - \theta) \cdot b \cdot r \cdot d\theta = b \cdot r \cdot \int_{-\theta_0}^{\alpha + \theta_0} B_r(\theta) d\theta$$

Then, finally,

$$\frac{\mathrm{d}\Phi}{\mathrm{d}t} = \frac{\mathrm{d}\alpha}{\mathrm{d}t} \cdot \frac{\mathrm{d}\Phi}{\mathrm{d}\alpha} = \omega \cdot b \cdot r \cdot \frac{\mathrm{d}}{\mathrm{d}\alpha} \int_{\alpha-\theta_0}^{\alpha+\theta_0} B_r(\theta) \,\mathrm{d}\theta = \omega \cdot b \cdot r \cdot \left(B_r(\alpha+\theta_0) - B_r(\alpha-\theta_0)\right)$$

which (after multiplying by the number of turns and up to the sign) gives the voltage U induced in the coil. In the experiment checking the model a square coil of a side of 1.2 cm and 100 turns was used. The coil was placed at distances r = 7.5 cm, 9.0 cm, 11.5 cm, 15 cm and 20 cm from the centre of the magnet. The magnet was rotated around its centre around the axis perpendicular to the long axis of the magnet (as it was indicated in figures above). The whole experiment was made as simple as possible – in fact, the magnet was rotated just by turning the axis by hand! Of course, in this case the rotation slows down making the period longer and the amplitude of the voltage smaller but when looking just at 1-2 periods we may neglect the fall of angular velocity ω . The voltage was measured and recorded by a Czech school computer measurement system called ISES with sampling frequency 2 kHz. The data were exported and then processed in MS Excel, in which also the values predicted by our model were computed. The results are shown at fig. 11. To measure the voltage for larger distances of the coil reliably would require a stronger magnet and/or higher angular frequencies and/or measurement in the environment with less electromagnetic noise. Still, it is clear that:

- Our model (simple enough for students at introductory university level) provides results that fit quite well to measured data.
- Both the theory and the experiments indicate the induced voltage would be harmonic function of time but only in case the coil was far enough from the magnet. (And in this case, of course, the maximum voltage would correspond to the position in which the magnet is perpendicular to the direction to the coil.)





 Fig. 11. Voltage (in mV) induced in the coil for various distances r of the coil from the centre of the magnet
– comparison of the theoretical model (solid line) and the measurements (squares)

5. Another way how to look at the problem: the multipole expansion

The problem discussed in this article may also serve as an illustration of another way how to describe the field, namely that of multipole expansion. Let's mention it very shortly, not going into details. The scalar magnetic potential of the non-elementary dipole described above (see fig. 8) may be (for r > a) expanded into the power series in (a/r)n. The angular dependence is described by Legendre polynomials $Pn(\cos a)$. Due to symmetry of the source (the dipole), the expansion contains just terms with odd values of

n. Terms with n = 1, 3, 5, correspond to dipole, octupole, etc. field. To compute radial component Br it is sufficient to derivate magnetic potential according to r. This gives

$$B_r = k \cdot (a/r)^3 \cdot \left\{ P_1(\cos \alpha) + 2(a/r)^2 P_3(\cos \alpha) + 3(a/r)^4 P_5(\cos \alpha) + \ldots \right\},\$$

where k is constant. For a small coil of the area S we can approximate the magnetic flux through it as $\Phi = B_r$, so for the voltage $U = -d\Phi/dt = -\omega d\Phi/d\alpha$ we obtain

$$U \doteq -S\omega \frac{\mathrm{d}B_r(\alpha)}{\mathrm{d}\alpha} = k \cdot S \cdot \omega \cdot (a/r)^3 \cdot \sin(\alpha) \cdot \left\{ 1 + 2(a/r)^2 P_3'(\cos\alpha) + 3(a/r)^4 P_5'(\cos\alpha) + \ldots \right\},$$

where P_3' and P_5' are derivatives of Legendre polynomials and we used the fact that

 $P_1'(x)=1$. Of course, $\alpha = \alpha_0 + \omega t$. Fig. 12 illustrates how the terms of the multipole expansion put together to approximate the resulting profile of the voltage.





Of course, all this is rather mathematics but it can clearly show to students that:

- A coil far from the magnet will really produce a harmonic voltage $\sim sin(\omega t)$ with the frequency equal to the frequency of rotation. (All other terms in the expansion being negligible in comparison with the dipole term.)
- For a coil closer to the magnet the further terms distort harmonic behavior. (Further analysis would show that there are higher harmonics $\sin(3\omega t)$, $\sin(5\omega t)$, etc. with their amplitudes rising as the coil approaches the magnet.)
- The multipole expansion is a useful technique how to tackle the problem.

6. Conclusions

What can be seen as interesting at the problem described here?

- The experiment is clear and simple.
- It provides unexpected and at the first sight strange result.
- Yet, the result may be qualitatively understood without any hard mathematics.
- The problem may be discussed and solved at various levels.
- Even a quite simple model provides results in good agreement with measured data.

Therefore the experiment and its model described above may well serve as an inspiration for a lab, small project or "inquiry" both at high school and at introductory university level. The experiment does not require any special hardware; any school CBL system may be used to measure the data. One can even speculate about using sound card input and some freeware program as Audacity for the measurement, but the data might be distorted due to fact that this input usually cuts off low frequencies. Of course, both the experiment and its model can be improved and changed in various ways. The measurement may be done more precisely by using stronger magnet and higher rotational frequency. We can use larger coils and magnets of other shapes. The model could be adapted to provide results for longer coils etc. But even without these improvements the experiment and the model can be used for an interesting small project for students.

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[1] http://kdf.mff.cuni.cz/~dvorak/articles/RotatingMagnet_GIREP2006.pdf (cit. 11. 10. 2006)

Modelling transitions between order and disorder in a Remotely Controlled Laboratory (RCL)

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Abstract

Order-disorder phenomena play a significant role in research as well as in everyday technologies. Examples are the melting of solids or the transition of magnets from ferromagnetic to paramagnetic state. Order-disorder transitions in solids are experimentally studied by scattering experiments (*e.g.* particle or x-ray diffraction techniques).

Modelling of order-disorder transitions (continuous or discrete) can be easily performed by using visible laser-light diffracted by specially designed objects. Starting with the introduction of an ideal lattice model, *i.e.* diffraction object with regular arrangement of subunits, disorder can be introduced by independent variation of several parameters of the subunits: distance between adjacent units, size, shape, "superstructure" of units etc. The resulting diffraction pattern can be directly observed on a screen and, furthermore, it can be evaluated with respect to parameters of the model.

The experiment is set up as a Remotely Controlled Laboratory (RCL) experiment, that is an experiment which can be carried out over the Internet. The user is allowed to change the diffraction objects and he or she can observe and record the diffraction pattern via web cam.

1. Introduction

Treatment of wave optics in secondary school physics takes place with special emphasis of description and explanation of diffraction on slits, double slits and grids. Typically, determination of wavelength of the light source (laser), of position of minima and maxima of the diffraction pattern and of the grating parameters are in the focus of the lessons. Only sometimes, the topic is finished by the discussion of the intensity distribution utilizing Feynman's vector formalism in a qualitative manner. Later on, wave optics comes back into the lessons when dealing with solid state physics or the more related crystallography, in particular, when dealing with Bragg diffraction and determination of lattice constants.¹¹

In the following, we present an experiment which, on one hand, allows students a qualitative approach to modern crystallography beyond the standard topics like determination of lattice constants in ideal cases and so on. For this purpose we replace the 3D x-ray diffraction technique by an optical analogue, that is diffraction of laser light (by using a cheap laser diode) on 2D models (representing the atoms or molecules of a real solid state lattice). Instead of x-ray scattering at the electron cloud of real atoms or molecules, in the model the scattering of light at motifs of varying shape and arrangement is applied. On the other hand, this experiment can be used to demonstrate and discuss order-disorder transitions on a microscopic level. The first perspective - going beyond standard topics - has several advantages if treated in school:

- It gives an opportunity to introduce crystallography without scare of hazardous experiments, since visible light of relatively low power is used in the model ("optical crystallography"). In particular, as an RCL there is absolutely no risk.
- By comparing the diffraction pattern and the structure of the diffraction objects the students are required to make qualitative or quantitative (depending on the level) statements about the causal relations.

¹¹ Although we have the German situation of curricula in mind, physics topics in secondary schools in other countries seem to be quite similar.

- The reduction from 3D crystallography using x-rays to 2D "optical crystallography" using light avoids complications due to absorption, multiple scattering etc.
- Students' concepts about scattering and diffraction will be proven and can be deepened in a more flexible way.
- Going from 1D diffraction objects (*e.g.* slits) as they are typically applied in school physics to 2D objects contributes to consecutive knowledge preparing for physics study, but without demanding the pupils.



The second perspective – order-disorder transitions – can be pretty nice modelled by this experimental design of "optical crystallography". Examples from everyday-life are:

- melting of ice (transition from crystal to liquid, increase in entropy),
- heating a solid (increase of displacement due to increase of thermal energy of the constituents),
- liquid crystal displays (disorder-order transition by applying an electrical field),
- change of magnetic properties above Curie temperature (*e.g.* transition from ferromagnetic to paramagnetic state).

Students in secondary school (age \sim 16-18) are familiar with those phenomena although they do not know about the physics behind, in particular on a microscopic level. Therefore, the relation to everyday-life may give an opportunity to motivate students for the topic "order-disorder" and the experimental approach of "optical crystallography" if treated in a context based method. Furthermore, we believe this topic to be appropriate for the students to perform a kind of "mini-research" at school level.

Diffraction objects were designed by a computer algebra program, which then have been reproduced as positives and, further on, developed by photo imaging techniques through the press department of our university.¹² The procedure to generate diffraction objects on slides have been previously described by Koppelmann.

¹² Details about the procedure (and the diffraction objects) can be obtained from the authors and will be publishd elsewhere.

2. Learning unit on order-disorder transitions

Fig. 1 gives an overview of the steps within the learning unit with respect to the diffraction objects applied experimentally. Basically, one has to start with an introduction to the model and its relationship to crystallography depending on foregoing tasks like discussing the results of wave optics (about 1D objects) as mentioned above. This procedure contains, *e.g.*, the reduction of the 3D problem to a 2D problem. In addition, it should be clearly pointed out that the diffraction pattern obtained from crystals corresponds to that one of a perfect lattice which is modulated by the (varying) motifs.

- Learners are required to choose an appropriate model of order-disorder transition on the basis of didactically prepared study guide.
- The changes of the diffraction pattern observed by the learner leads him or her to discuss the structure of the diffraction object.

In the following sections we will briefly discuss several aspects in more detail.

2.1 Diffraction by an ideal model

Introduction to the model

Models are - in general - aimed to describe reality. Therefore, one has to start with reality when describing nature by an appropriate model.¹³ From a didactical point of view, models have to be developed by the students itself to ensure their deeper insight in a given topic. There may be several approaches to reach the topic crystallography. We would like to sketch only one way: starting with the discussion of Laue diagrams (concerning that "diffraction and interference" have been treated in lessons on "wave optics") to clarify where the high intensity reflections are coming from, we can then turn to the model of a crystal lattice and, later on, it should be made obvious for the students to vary the structure of an ideal crystal in terms of disorder. Disorder then can be introduced by varying the periodicity and other properties of the crystal lattice. It should be pointed out here that each step can be supported by simple experiments or convincing considerations. In the following we describe the individual steps according to Fig. 1.

Construction of a lattice

Fig. 2 depicts the diffraction pattern if going from two holes (notation 2x1, Fig 2a) up to 50x50 holes (Fig. 2d). By observing the evolution of the pattern when adding holes in *x*- or *y*-direction one can state that the diffraction pattern gains intensity (more correctly brilliance in terms of crystallography). Going to an infinite number of holes with almost zero diameter we then expect a perfect point diffraction pattern as a limit of an ideal crystal lattice.

In addition, the relation between the point lattice and its reciprocal lattice can be studied by variation of the angle between the 2D lattice vectors.

Modelling diffraction by real atoms

So far, we considered lattice points (~



atoms) as infinitely small (ideal point lattice). In real crystals the size of atoms or molecules can not be neglected, furthermore, the shape of molecules introduces additional features to the diffraction pattern. To model these peculiarities we designed diffraction objects with close

¹³ For the moment, it does not matter on which mathematical level the "description of nature" will be done.

relation to real objects (*e.g.* circle to model rare gas atom, hexagon to model benzene). Students are required to express their expectations and to examine these by experiment.

Modelling diffraction by real crystals

As can be seen by Fig. 3 the intensity distribution of the ideal lattice is modulated by the diffraction properties of the single object (motif), that is in the case of circular holes (~ rare gas atoms) a radial distribution of intensity, and in the case of a hexagon (~ benzene) a sixfold symmetry of the diffraction pattern. Since we have to deal in real



crystals with an enormously large number of atoms or molecules (instead of our diffraction objects for modelling) the peculiar modulation gains intensity. The student's task here is to discuss the impact of the motif of a given atomic/molecular structure on the diffraction pattern, assuming an ideal crystal.

It can clearly be seen that the more complex a molecule is (*e. g.* circle -> quadratic -> rectangular -> hexagonal) a more complex diffraction will appear. However, the discussion of symmetry properties can be done in school (qualitative) as well as in university (quantitative). At university level, in particular in advanced physics studies, these experiments are useful to make Fourier transformation comprehensible.

2.2 Examples of order-disorder transitions

Thermal motion of atoms in a lattice (Fig. 1: step C)

Thermal motion of atoms in a crystal lattice is statistical and - in the simplest case averaged over time it is isotropic. Hence this motion can be modelled



by circular diffraction objects with different diameter whereby the amount of thermal motion (~ temperature) corresponds to the diameter of the objects. Fig. 4 shows the result of the experiment: the higher the temperature (increasing object diameter) the closer the diffraction rings. In fact, crystal structure analysis has to struggle with thermal motion of the crystal's constituents, and typically thermal motion of atoms in crystals is represented by so called thermal ellipsoids. Similarly, the size of atoms or spherical molecules (*e.g.* rare gas atoms He -> Ne -> Ar -> Kr -> Xe) can be modelled in this way.

Solid-Liquid/Gas Transition (Fig. 1: step B)

As an example for solid-vapour transition we modelled a regular 2D lattice containing quadratic motifs by varying statistically the deviation of the "centre of mass" from the ideal lattice points. The result is shown for two distinct but considerable different values of the deviation (Fig. 5). At first sight it is clear that the fine structure representing the regular lattice disappears. Disorder (~ liquid) destroys the coherence, what means that the phase differences of the waves cover a range from 0 to 2π . However, the diffraction pattern due to the "atoms" is still observable since the individual motifs, which are still present, are responsible for it. A simulation of solid-liquid transition, on the other hand, requires the model objects to have a local order remaining, i.e. the next neighbour distance to be similar to the solid case.

Fig. 5. Diffraction pattern of a square lattice build by squares of zero variance (a) and statistical deviation from perfect lattice points (b)

h

Nematic phase of liquid crystals (Fig. 1: step D)

As a model for nematic liquid crystals we have chosen rectangular motifs. Disorder is introduced in this case by variation of the position of the "centre of

mass" on one hand and by variation of the orientation of the rectangles on the other hand. Since there is no lattice order present in the sample we can observe only the diffraction pattern of the rectangular motif. With increasing



orientational disorder the diffraction pattern comes closer to a ring pattern representing an averaged distribution of rectangular orientation like in the case of circles (Fig. 6).

a

3. Realization as a Remotely Controlled Laboratory (RCL)

The concept of an RCL is for a user with a computer (client) from a distant location to remotely control an experiment set up at a specific location (Fig. 7) by means of a web browser. When implementing an RCL one has to take care that the user is able to follow the ongoing real experiment and changes of parameters via web cams as well as gathering the data of



the measurements as fast as possible online. Operating the experiment should be as authentic and transparent as possible for the user, *i.e.* the experiment should come across as a common real experiment carried out in lessons or in lab courses.

Generally, remote controlled labs offer several advantages:

- access time 7 days 24 hours,
- sharing resources between universities and/or schools,
- opportunity of experimentation which is otherwise not available,
- flexibility in performing those experiments (*e.g.* in distance education).
- In particular, experiments on diffraction and interference in school are limited:
- due to the time available which allows only demonstration experiments,
- therefore, mostly a qualitative approach is applied,
- poor variation of parameters,
- not going into the subject thoroughly including the topics discussed above.

The presented experiments in combination with study guides can serve as self-learning units for students as well as for teachers when preparing lessons on non-standard topics.

Design of the RCL experiment

This experiment makes use of a laser with wavelength in the visible region (as a prototype we used a solid state laser with ca. 530 nm wavelength and > 10 mW power). In order to illuminate as many as possible diffraction objects D at the slide



(resolution) the laser beam diameter is expanded by a factor of 6 by means of lenses (L_1 and L_2) in a telescope arrangement (Fig. 8). Clear observation of the diffraction pattern via web cam (W_1) makes necessary a focusing lens (L_3) providing an image on a screen (S). To allow a remote user to compare the diffractive objects with their diffraction pattern a lens (L_4) can be placed at the position of L_3 . This lens generates an image of the object at the screen. Simultaneous observation of objects and related pattern is only possible if a beam splitter is placed into the optical bench.

Diffraction objects and lenses, as discussed above, are placed on rotating discs which can be easily controlled by the remote user via his or her web browser. The experimental configuration as well as the diffraction pattern can be observed via web cams (W_2, W_1) which transfers the data in approximately real time (depending on the connection speed).

4. Conclusion

Diffraction and interference is one of the most important topics in secondary school physics, it appears when treating wave optics and solid state physics. However, when treating these topics in school (or in the first semesters of university) standard approaches (*e. g.* 1D cases) are generally applied. A more thorough treatment of diffraction and interference related to everyday context delivers another approach: Modelling of solid state structures, as a first step, and modelling of order-disorder transitions, as a second step, which supports the students' insight in microscopic properties of matter. Moreover, by means of realization of these experiments as an RCL in combination with study guides and learning units students gain the opportunity in explorative learning. Teachers, on the other hand, are provided with material which enables them to teach non-standard topics in the context of everyday-life. Although we could not discuss the learning unit in detail, we think that the presented experiments are convincing. Not only students in school but also students of the first semesters in physics and students in advanced physics studies may benefit the advantages brought by these experiments, in particular, distance learners will benefit from these remote experiments.

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Experience with the use of MBL in physics teaching

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Abstract

The contribution deals with the use of MBL in physics teaching. Teachers at secondary schools usually do not have the technological background and capacity to transform traditional lab activities into computer-based lab activities. Therefore we started our project named Labworks in MBL. The aim of the project was to design computer-based lab activities for the second year of grammar school (students aged 16-17), prepare worksheets for active learning in MBL, gain experience in the field of pedagogical methods, role of the teacher in the class, instructional materials, etc. and test the effectiveness of teaching in MBL. The seven activities which were developed were: Introductory labwork, Thermal processes of an ideal gas, Thermal expansion of water, Changes of state, VA characteristics of a battery, VA characteristic of different elements, Thermal dependence of resistance. Before each session students answered a pretest. Then students worked 90 minutes in groups of two or three to carry out the experiment guided by the work sheets. After the measuring procedure they analyzed the graphs, created new graphs, determined the values of different physical quantities typical for the physical process and they answered the questions and problems. Some time after the labwork they answered a posttest. The paper will discuss experiences, results of research regarding the effectiveness of teaching with MBL, and will make recommendations regarding the pedagogical methods used.

Introduction

In the past years microcomputer-based laboratories (MBL) are slowly but gradually becoming a part of physics teaching in Slovakia. There are several projects supporting the selected schools with the appropriate technical equipment (mostly IP COACH system) necessary for this way of teaching (Coach webpage). There is no doubt that MBL tools provide a powerful way for students to learn physical concepts. With the help of a microcomputer interface and sensors connected to the computer and software for data collection and their processing and analysis the computer changes to more than a measuring tool. There are many researches showing the positive influence of MBL tools on physical concept understanding. One of the factors responsible for the positive results is the students' active engagement in their process of learning (Thornton, 1992, Ješková, 2004). On the other hand, our educational system in physics teaching is not prepared for this way of teaching yet. Teaching in MBL with students' active participation requires different methods and also new teaching materials that are not available for the teachers that were graduated several years ago. Trying to fill in this gap we realized a pilot project "Laboratory measurements with the IP COACH system" with 208 students participating at four different measurements in April and June 2005 (Ješková, 2005). Gaining a lot of useful experience we decided to run a large-size project in the school year 2005/06 aimed at the second-class grammar school students. In the contribution we present the project, the designed labworks and the corresponding instructional materials and the results of the pedagogical experiment in the field of the effectiveness of the active learning MBL measurements.

Project Active learning MBL for the second-class grammar school students (Labworks in MBL)

Project background and goals

The project Active learning MBL for the second-class grammar school students has been developed as

a natural continuation of a pilot project "Laboratory measurements with the IP COACH system"

(Ješková, 2005). With the essential technical background (laboratory with 12 computers, 6 computers

equipped with interface, sensors and IP COACH software) tested in the pilot project and experience in

the field of teaching methods and instructional materials used in teaching we had a good starting point

to create a real active learning MBL environment. The main goals of the project are as follows:

- to design and prepare a set of MBL measurements corresponding to a grammar school secondclass curriculum with the emphasize on students' active learning,
- to create instructional materials to the designed measurements with the emphasize on students' active learning,
- to test and verify the quality of designed measurements and instructional materials in the process of teaching,
- to gain experience with the way of teaching with the emphasize on students' active learning concerning teaching methods,
- to realize pedagogical experiment in order to show the influence of active learning in MBL on physical concepts understanding,
- to find out the students' and teachers' attitudes to this way of teaching.

Project organization

The project was realized during the school year 2005/06. There were together 7 different measurements and one additional optional measurement designed (tab.1). Teachers could apply for a certain measurement on the web page: http://www.physedu.science.upjs.sk. They filled in an electronic application to set the school, number of students, and contact address. There were together twelve 90-minutes sessions available, i.e. there were together about 150 students participating at each measurement. Maximum number of students for one session (18) was divided into 6 groups. Each measurement was lead by our teacher.

	Торіс	Time schedule
1	Introductory labwork	October
2	Ideal gas laws (Boyle's law, Charles law)	November
3	Changes of state (melting, solidification, evaporation, boiling)	January
4	Thermal expansion of water	February
5	Ohm's law for the closed circuit	March
6	Thermal dependence of electric resistance (semiconductor and conductor)	April
7	VA characteristics of different elements (linear metal conductor, bulb, PN junction)	May
8	Why do the bulbs fade? (optional)	June

Tab.1:	Topics	and	time	schedule
	100100	****	*****	

After all the seven realized measurements we invited students – voluntaries who were interested in physics to take part at an additional optional measurement designed as a real self-controlled labwork guided by the instructions in the worksheet. The labwork was aimed at the study of the behaviour of bulbs connected in series (parallel) in a direct electric circuit. There were three sessions with 24 students participating.

Labworks and instructional materials

One of the main goals of the project was to create the series of computer-based labworks for the grammar school second class corresponding to the current curriculum and high quality instructional materials that would respect the active learning elements. Respecting the experience from the pilot project (Ješková, 2005) we designed an introductory labwork aimed at the basic skills in the physical quantities measuring and processing occurring in the further measurements (voltage, current, temperature, pressure). In the instructional materials development we were guided by the outcomes of the physics education research. The results in this field show that students can learn physics concepts more effectively through guided activities enhanced by the use of MBL tools (Thornton, 1992, Ješková, 2004). Respecting these facts each measurement except from the introductory labwork was realized with the following structure:

- Physical principle of the measurement revised by the teacher. All the participating students were already familiar with the topic.
- Short introduction about how the measuring of the physical quantity (voltage, current, temperature, pressure) is realized with the help of the MBL tools.
- Setting the apparatus.
- Students' prediction about the measurement result. The measuring procedure. The results are presented in the form of diagrams.
- Measurement results analysis, questions and problems to solve, students discussion with their peers or with the teacher. The most important part of the labwork guided by the instructions in the worksheet requiring students' active participation. Printing out the gained results.
- The measurement summary controlled by the teacher pointing to the most important results and conclusions. Discussion about the possible inaccuracies and errors.

Experience and findings

Labworks and instructional materials and students' active learning in MBL

The students realized all the designed labworks without any major difficulties. The proposed labwork structure proved to be suitable for the designed measurements. There were only a few minor modifications in the designed labworks. In the case of the ideal gas laws we had to shorten the labwork from three laws verification into two laws (Boyle's law and Charles' law) and in the case of the thermal dependance of resistivity we had to revise the measurement sequence. The instructional materials were promptly modified within the project realization. Most of the modifications were concerning the result analysis although the worksheets were prepared taking into account the pilot project findings. During the project realization we found out that the students adapted to self-controlled active learning with difficulties. In order to make them think, reason and discuss about the given problem they needed more detailed guide presented in the worksheet that was modified according to instant and direct experience. In addition, the instructional materials were adapted the way that all the instructions concerning the informatics skills (how to scan the values, create, edit a graph, do a function fit, etc) were moved to the back of the worksheet leaving the main part independent from the computer system and software used.

In the last optional labwork students had to design the experiment verifying the bulbs behaviour connected in series (parallel) in a dc electric circuit. Furthermore, they had to connect the interface in order to measure voltage and current and set an IP COACH activity that enables to collect and process the data. They had to create new diagrams and find out the physical quantity determining the bulb brightness. These set of activities proved to be quite difficult even for the best students and most students definitely needed the teachers' help. There were just a few individual students that were able to work by themselves without a significant help.

The effectiveness of the active learning MBL measurements

In order to get feedback about the influence of active learning MBL on the knowledge concerning the content of the measurement the students filled in a pre-test just before the labwork and a post-test about one or two weeks after it. The pre and post-tests were administrated in the case of each labwork except from the introductory and the changes of state labwork. Since the result of the measurement is presented in the form of graphs, students were expected to be able to read from the graph and get additional information from it with the help of computer tools (slope, function fit) to understand the analysed phenomenon. That is the reason why most test questions were connected to graphs since we expected a positive influence in this field. The results (tab.2) indicate a positive shift after each labwork. This is a good signal but on the other hand it is hard to maintain it is definitely just because of the active learning MBL measurement.

Topic	Percentage of correct answers						
Topic	Pre-test	Post-test					
Ideal gas laws	60,9 %	86,4 %					
Thermal expansion of water	62,4 %	84,7 %					
Ohm's law for the closed circuit	54,1 %	71,3 %					
Thermal dependence of electric resistance	67,1 %	82,7 %					
VA characteristics of different elements	76,7 %	86,3 %					

Tab.2: Results of pre and post-tests

Students and teachers attitudes to active learning in MBL

The students and teachers attitudes to the active learning MBL were verified with the help of a student's and teacher's questionnaire. It was filled in after realizing all the seven designed measurements.

84,8% of participating students considers the computer-aided measurements interesting. 88,33% of students finds them even more interesting than traditional ones (fig.1).



Fig.1 Questionnaire items

Students answered the question asking about the fact if these labs enhance their active learning differently. There is no dominating answer. That is the point we have to take into account and think over the methods used in teaching in MBL. The reason why they say this is in the fact students think computer substitute their work in the field of graphs creating. Many of them think that the labwork ends when the measurement itself is done. They do not understand that just after that the real process of physical thinking starts. They were often happy the measuring procedure was over and they did not put too much effort into the results analysis. For us it means we have to train them in active self-controlled learning more often (fig.2).

Fig.2 Questionnaire items



On the other hand 75% of students think the questions in worksheet made them think more than usually. 85% of students also confirm they discussed the problems with their peers. 75% of students states that the worksheet were clear and understandable (fig.2, 3).



Fig.3 Questionnaire items

75% of students claim that the computer itself made the measurement attractive. The questions concerning the difficulties to work with the software show that 75% of students do not consider it difficult. 71% states they would be able to prepare their own activity in COACH (fig.4).

Fig.4 Questionnaire items

Since in many experiments students had to use the fit function tool in order to fit the measured data with the appropriate function we asked them to explain this procedure. 77% clearly understood what this procedure is about.

In the last question we asked the students to design a computer-aided experiment that would help to find out which thermo flask to buy for the mountaineers. 65% of students came up with the measuring procedure and they also drew the expected graphs according to which they would decide.

Since the teachers of the participating students were present at the project they filled in a questionnaire after the project realization. They attitude to the project is highly positive. All the teachers consider the project very interesting. They think the level of the worksheets used by the students was very high. They see the usefulness of this type of experimentation mostly in the field of the measurement accuracy, comfortable and fast data processing that enables to concentrate the students' attention to the data analysis and discussion about the gained results. They also think that computer used in physics can attract also the attention of the students that are not too good at physics.

All of the teachers also think that this way of teaching and the worksheets led the students to their active participation in the process of learning. On the other hand they had to adapt and get used to this way of learning.

Conclusion

The project realization fulfilled our expectations. We succeeded in preparing seven active learning MBL measurements for the standard conditions of the grammar school second-class. The verification on the sample of approx. 150 students proved the suitability of the designed labworks and instructional materials and the pedagogical experiment indicates a positive shift towards the better understanding. The final version of the instructional materials is presented on the web: http://www.physedu.science.upjs.sk. We hope that the project results and the materials available on the web will definitely find its users. In the next year we are planning the continuation of the project with the physics teachers' active participation. Firstly they come to realize a measurement in MBL environment and then they will conduct the measurement by themselves with their students. We hope that this way of teaching will find its fans among the teachers and the MBL tools will help students to understand physics better and it helps to change their attitude to the subject.

Acknowledgments

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Computerized Registering of the Contact Pressure in Press-Joints

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Abstract

Contact pressure is an important parameter for a press-joint working and it should be in a preliminary determinate range. If the pressure is lower there is a risk of a pressjoint skid during the operation and if the pressure is higher – there is a risk of an extra load, in advance and accelerated destruction. Because of that it's of great importance to make the students acquainted beforehand and trained for a successfully measurement of the contact pressure in the press-joint by ultrasonic non-destructive methods. Ultrasonic conductivity is measured through the contact layer of the pressjoint. A conclusion about its pressure at particular point could be taken depending on the magnitude of the reflected signal. Recapitulation of the digit values in a specific way gives the possibility of evaluation of the main press-joint parameters, which are of great importance for the practice.

Knowledge in the field of Physics and Engineering is used for the quality evaluation of the joints.

Reiterated mechanical operations and mathematical calculations are used. The students find it difficult to create notion about the load in the press-joint, because they pay a lot of attention to the repeated operations and calculations as well to the drawing of graphic dependences between the different parameters. Modern computer techniques enable the use of automated control systems, calculating and visualizing systems. These possibilities are positively evaluated in education where technical equipment is limited. The student can initiate the great part of the computer dialog. In addition, not only the final result is important but also the way of it's obtaining for the purpose to rationalize working processes. Thus the practical research on the problems of press-joints is important in the training in the frame of the workshop of a wide range of specialists.

The purpose of this work is to present a technical decision and short methodic of quality parameters determination in press-joint and conducting of a workshop with the help of computer techniques. The research is conducted into Machinery Elements Lab of Todor Kableshkov Higher School of Transport and intended for students' training in herenamed and other European schools. On the base of a present laboratory task the students can receive a real notion about the physics phenomena and properties application in a specific area of engineering.

Theoretical part

The contact pressure of a press-joint is measured successfully by using well-studied physical theory of wave spreading in strong body and their reflection from two surfaces' boarders. Parameters of the reflection depend on the size of contact pressure p as well on the specific conditions of the contact, incl. surface treatment, contact lubricator availability etc. [1,2]. Established practice shows that the most effective are ultrasonic waves of 4 - 10 MHz formatted perpendicularly to the contact surface from a specialized probe. The ultrasonic signal reflected from the contact surface is examined.

The principle of contact pressure measuring is shown in Fig.1. Its realization scheme is shown in Fig.2. A longitudinal ultrasonic wave with power E_x is sent from the probe 3 to the contact surface between the axis and the bush. A portion of the wave power is reflected (E_y),

other portion (E_z) passes through the contact layer. Reflection factor on power R_x of the wave is calculated as follows:





Fig.1 Method of measuring

(1)

Fig.2 Measuring scheme; 1 – axis, 2 – bush, 3 – probe

$$R_x = E_v / E_x$$





Fig.3. Scheme of wave amplitude measuring before (A_0) & after (A_1) pressing of the bush and axis.

Fig.4. Principled chart of contact pressure *p* determination.

and measured through the waves' amplitude. For that purpose the probe 3 (fig.2) is placed normally on the outer surface of the bush and is used for generating and measuring of the reflected ultrasonic waves amplitudes consequently before (A_0) and after (A_1) of the bush and the axis being pressed (Fig.3). For practical needs the parameter α is being formatted:

(2)
$$\alpha = 20 \left| \lg A_1 / A_0 \right| = \sqrt{R_x}$$

which is a medium of contact pressure p calculation. Diagrams similar to those of Fig.4 are used. They are received by an experimental ultrasonic research of contact layer within the limits of drowning out of the contacting materials. Factors like total height of roughness $\sum Ra = Ra_1 + Ra_2$, where Ra_1 and Ra_2 are height of roughness of the contact surfaces of the axis and the bush as well the contact conditions. These measurements are conducted under permanent frequency of ultrasonic wave. Fig. 5 & 6 express typical experimental results achieved at frequency 5 MHz [1]. Correlative functions are introduced as follows: - height roughness indication

(3)
$$\alpha = -4.1302.ln(\sum Ra) + 10.662$$
, dB

- type of contact indication

In presence of axle oil:

(4) $p = 0.4409 \cdot e^{0.1967\alpha}$, at dry contact:

(5) $p = 0.1022 \cdot \alpha^2 - 0.1557 \cdot \alpha + 3.2392$, at MoS₂ presence : (6) $p = 0.0873 \cdot \alpha^2 + 1.1233 \cdot \alpha + 1.7683$, at oxides presence : (7) $p = 0.0566 \cdot \alpha^2 + 1.9322 \cdot \alpha + 2.0366$.



Fig.5 Dependencies between the parameter α and total roughness height $\sum Ra$ at p = 300MPa.

Fig.6. Dependence between parameter α and pressure *p*; contact conditions: 1 – axle oil; 2 –dry contact; 3-MoS₂ presence; 4 – Oxides presence.

Correlated dependencies as they were determined are used for contact pressure p determination in the press-joint.

Experimental part

To obtain sufficient accuracy in p measurement an encircling movement of the outer cylindrical surface of the bush is prescribed by means of ultrasonic probe when the last is strictly positioned towards surface and being registered. Scheme of the stand for pressure measuring in press-joints is shown in Fig.7 with following signs: 1 electric motor, 2- gearing, 3 & 4 screw transmissions, 5 & 6 centres, 7 sink with contact lubricant, 8 – ultrasonic sensor, 9 - ultrasonic fault detector, 10 - supply block/pit, 11 - computer system for signal registration. This stand is working as follows: Press joint 12 is tightening to centres 5 & 6 by screw 4. Probe 4 with frequency 5 MHz is positioned toward the outer surface of the bush by gear 3. Special props are installed for its constant spacing from the surface. Fault detector 9 generates to the sensor 8, after that it receives ultrasonic signals. Electric motor 1 transmits to gear 2 and connected to it screw 3 the sink into linear direction of press-joint. Special props are installed for its constant spacing from the surface. Fault detector 9 generates to the sensor 8, after that it receives ultrasonic signals. Electric motor 1 transmits to gear 2 and connected to it screw 3 the sink into linear direction of press-joint. Additionally a sensor type MD-ULI is used for linear movement measuring of the sink 7 and sensor 8.Data about reflected from the contact surface signals and about the sink placement are registered simultaneously by means of computerized system. It consists of module CMC 3, software eProlab and a PC. Its scheme is shown in Fig.8.



Fig.7. Scheme of the stand for ultrasonic probe of a press-joint.

Fig.8. Scheme of the signal registering system.

The movement of the probe is being registered with the contact lubricant, and measured electrical values are simultaneously registered in dependence with function of this location, results are visualized etc. Signals of reflected ultrasonic wave from the contact surface are registered in an analogue state (voltage) and a shift sensor in a digital state (time). The entire probe of a press-joint is made by angular/angle-spin with equal values round the centres 5 & 6 and subsequent measuring of the signal from contact length.

Photo of the computerized system is shown on Fig.9.



Fig. 9. Photo of the computerized system for value of the computerized system for val

The reflected wave from inner surface of the hub before the pressing is registered and written down before the measuring of amplitude A_0 .

Typical results of measuring the results after the probe of a press-joint with dimensions $d_1 = 24$ mm, d = 42 mm, $d_2 = 80$ mm and b = 140 mm are shown in Fig.10. Axis and hub are made of steel 40X and are volumetric tempered up to hardness 42 - 44HRC. Roughness height is $Ra_1 = 0,12 \ \mu m$ and $Ra_2 = 0,22 \ \mu m$. This joint is prepared by hub heating and lacking of lubricant between contact surfaces. A section 40 mm long is studied. For obtaining quantity results about pressure p additionally is introduced dependence for reducing the measured pressure to reflected wave amplitude Fig.11. The received correlation dependence is of type 8, which describes the experimental results very well.



Fig.11. Experimental dependence for the measured pressure setting into reflected wave amplitude



(8) $\alpha = 3,5647 + 0,1653.V + 0,0795.V^3$

On the base of the received values and correlation dependences (3-8) we can calculate contact pressure p. Typical results received by means of widespread software are shown on Fig.12. On the base of the received values and correlation dependences (3-8) we can calculate contact pressure p. Typical results received by means of widespread software are shown on Fig.12. Some irregularity of the pressure is available due to technological reasons of the processing on pressed axis and the hub.

Order of workshop conducting

1. The students insert the bush of the press-joint into the device. The feeler is fixed for the ultrasonic measurement the basic zero signal A_0 .

2. The press-joint is installed into the device. The feeler is fixed for the ultrasonic measurement. The filer is put in motion and the reflected signal from the certain section is measured.

3. The experimental results are visualized, recorded and printed.

4. Students make written reports.

Conclusion

Determination of the contact pressure in press-joint can be fulfilled by means of universal computing devices. They enable to automate the reiterated operations and students to acquire facilitate such different physical measurements practically purposed.

The obtained values successfully are manipulated by widespread calculating program and visualization of the results. An additional advantage of the herein presented work is students to obtain a real notion about the physics phenomena and properties in a concrete field of practice.

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Which side up? Falling bread revisited.

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Abstract

The problem of falling buttered bread, though solved by several authors already, still remains inspiring and interesting. Not only because the results found in literature sometimes differ a bit, but the problem may well attract students at both high school and introductory university level. Using todays common tools like camcorder and computer freeware the problem may be studied even experimentally.

The paper presents both a theoretical analysis of the problem (by means of numerical simulation) and its experimental study using video recording and videoanalysis. Comparison of our results and results of previous studies is mentioned; moreover, we explored also the influence of some further factors (especially moment of inertia of the toast).

1. Introduction

In this article we investigate the problem of a slice of bread put at the edge of a table so that it falls down (to, presumably, precious carpet). Is it really going to fall buttered side down? And is this due to physics or due to some mysterious Murphy's Law?



Fig. 1: Falling Landau-Lifshits textbook on classical mechanics (Note: The book is not buttered...)

Our intention to calculate the motion of falling bread is rather new. It was motivated by a presentation of this problem at a TV show. But, of course, the problem was investigated in several articles already.

Matthews [1] was probably the first who tried to tackle it. He considered the initial phase of the motion (before the free fall) just as the rotation of a thin board (lamina) around the edge of the table. He argued that the board (i.e. the bread) looses contact with the table nearly immediately after it starts to slide.

Bacon et al. [2], after mentioning approaches and results of [1] on few other articles, made a more detailed calculation of the motion of (both thin and thick) bread. He has shown that to describe the problem correctly, the phase of sliding must be taken into account, and arrived to results that agree with experiments. He also used analysis of videos of falling bread to determine the angular velocity of the bread.

What did we do:

In this article we show how the problem of falling bread may be approached in a way suitable to be used as project for students. We took a slightly larger wooden board than authors mentioned above (of length l = 20 cm – in fact, a normal slice of Czech bread really has such dimensions) and put it at the edge of a table with a quite small overhang. (The bread just-just

turned over the edge.) Then we investigated how the motion and landing result is influenced by various changes of parameters of the system, namely:

- Friction between "bread" our wooden board and the table. (To increase the friction coefficient we used sandpaper.)
- Moment of inertia J of the board actually, its gyration radius J/m. (We used iron weights either near the centre or at the edges of the board to change J.)
- The initial horizontal velocity of the board.

In treating the problem we will present numerical simulation of the motion of both thin and thick board, analysis of videos of real falls and a short comparison of theoretical and experimental results. Both the simulation and analysis of video enable to distinguish all three phases of motion – rotation, sliding and free fall. For brevity we will omit here simple and rough estimate at high school level, approximate analytical solution for the motion of a board pushed with a non-zero initial velocity and some simple considerations concerning scaling of the problem. These topics may be found in the full version of this article as we presented it at GIREP conference at web page [3] and will be also published elsewhere.

2. Equations of motion of thin bread

The "full" equations of motion of a bread slice may be derived from the change of momentum and angular momentum of the bread:

$$m\ddot{\vec{r}}_C = m\vec{g} + \vec{F}_p + \vec{F}_f, \quad \dot{\vec{L}} = \vec{M} .$$
⁽¹⁾

 \vec{F}_p and \vec{F}_f are forces by which the table edge acts to the

board. \vec{F}_p is perpendicular to the board, force \vec{F}_f , caused by friction, is parallel to it – se Fig. 3. For angular momentum only the component L_z perpendicular to x-y

plane is relevant. Here we will consider just the case of a board with negligible thickness. And, of course, we will now describe only the part of motion when the board is in contact with the table (the following free fall is same as in previous section).

Putting $x_C = r \cos \varphi$, $y_C = r \sin \varphi$, $L_z = J_C \dot{\varphi}$,

 $M_z = r F_p$ (see Fig. 2) into equations (2) we arrive, after some rearrangements, to final equations

$$F_{p} = \frac{J_{C}}{J_{C} + mr^{2}} m \left(g\cos\varphi - 2\dot{r}\dot{\phi}\right)$$
(2a)

$$\ddot{\varphi} = \frac{r}{J_C} F_p \tag{2b}$$

$$\ddot{r} = -\frac{F_f}{m} + r\,\dot{\varphi}^2 + g\sin\varphi \tag{2c}$$

Note: Alternatively we could derive eqs. (2) from Lagrange equations We could also take angular momentum and momenta of forces not to the centre of mass C but to the edge 0. (Students should realize that all these ways lead to the same equations!)

There are two phases of the motion before the board leaves the table:

a) rotation around the edge

In this case r = const. Equation (2c) then enables, after putting $\ddot{r} = 0$ into it, to determine the friction force F_f . This phase lasts while $F_f < f_s F_p$ where f_s is a coefficient of static friction.

Then the board starts to slide.

b) sliding

During this phase the friction force is $F_f = f F_p$ (we consider the friction to be Coulomb). The force F_p given by (2a) decreases with time. When $F_p = 0$, the board ceases the touch with the edge and starts to fall and rotate freely.



The equations of motion of a thick board can be derived in a similar way. They are slightly more complicated – for the brevity we will not present them here but we use them in simulations described below.

3. Numerical simulation

It is natural to solve eqs. (2) and similar equations for a thick board numerically. We tried to make the numerical simulation as simple and clear as possible and not to use any special system for solving differential equations. That's why we used the simple Euler method for solving (2). A part of the algorithm (for the sliding phase) illustrating the simulation is shown in the box. Here, Om and afi

```
REPEAT
    Fp = m*JC/(JC+m*r*r)*(g*cos(fi)-2*vr*Om)
    Ff = f*Fp
    afi= (r/JC)*Fp
    ar = -Ff/m + r*Om*Om + g*sin(fi)
    Om = Om + afi*dt
    fi = fi + Om*dt
    vr = vr + ar*dt
    r = r + vr*dt
    t = t + dt
    xC = r*cos(fi); yC = r*sin(fi); DISP
UNTIL Fp<=0</pre>
```

stands for $\dot{\phi}$ and $\ddot{\phi}$, vr and ar for \dot{r} and \ddot{r} . Some auxiliary commands are omitted for brevity. The simulation algorithm was in fact written and run in an old DOS-based computational system *Famulus* but it may be easily rewritten into any programming language like Pascal, Basic etc. or into a modelling system.

The used time step dt was typically 0.2 ms but 1 ms proved to be quite sufficient. The precision of the numerical simulation was checked by monitoring total energy of the board. It is constant during the rotation phase and decreases in the sliding phase – but its decrease can be compared with the work done by the force F_{f} . The computed position of the board was displayed every 20 ms to enable easy comparison with experimental data.

The initial conditions used in the majority of simulations were simple: $\varphi(0)=0$, $\omega(0)=0$, $r(0)=r_0$ (small initial overhang, typically several mm), $\dot{r}=0$. The final angle φ_{landing} and the angular velocity ω during the free fall were always taken as the main output. The ω values were also used to compare our simulations with the results of Bacon et. al. [2]. For the dimensions of the board used by these authors our simulation for both thin and thick board produced the results are in a complete agreement with those presented graphically at Fig. 7 in [2].

Fig. 3: An example of graphical outputs from our simulations



On Fig. 3, both positions of the board and graphs $\omega(t)$ (top one) and $\varphi(t)$ (bottom one) are plotted. The positions and values plotted in green correspond to the rotational phase of the motion, those plotted in red to the sliding phase and those in blue to the free fall.

4. Experiments and measurements

The processes of sliding and falling of the bread slice are too fast to be observed quantitatively without some form of data logging. In our case the datalogger was a standard digital camcorder. We followed a process that is sometimes called "the videoanalysis" – we took numerous recordings of the fall and then step by step measured positions of the board on each frame of the clip.

Fig.4: Different positions of the board (images extracted from one clip used for measurement)



Via a special method of image deinterlacing, the so-called bobbing, we could measure the positions of the board at a speed of 50 frames per second. We captured positions of three significant points on the board during its entire movement – the centre of mass (centre of the board) and the two ends of the board. The data were taken using the *Viana* [4] software, however any other free software tool for videoanalysis could have been used.

5. Processing the data

The measured data from *Viana* were exported into MS Excel and processed. For each position we calculated the distance between the centre of mass and the axis of rotation (i.e. the edge of the table), the distance between the board and the axis and angular velocity. From these values we could separate the three phases of the movement described in paragraph 2. a) At the phase of rotation the distance of the centre of mass and the axis doesn't change significantly. b) At the phase of sliding, the distance between the centre of mass and the axis increases but the board is still in contact with the axis. This can be recognized from the fact that the distance between the board (presented by a line containing the three measured points) and the axis is constant.

c) At the third phase, the free fall, the centre of mass moves with uniform acceleration g and the angular velocity of the board doesn't change. Note: To identify all phases is easy in theory. In reality it appeared that it is difficult to determine the exact times

of starts of phases b) and c) from experimental data. (Usually these times are overestimated.) One must be aware of this possible source of problem when comparing theory and experimental results.





The board left the table at an angle of about 60° - 65° .

Fig. 5: The set of data from one measurement



Each threesome of coloured points represents the position of the board at one instant. The axes are scaled in meters.

6. Some results

Comparison of main theoretical and experimental results is presented at figure 7. It shows both final angles at which the board hit the floor and its final angular velocities.



Fig. 7: Comparison of main theoretical and experimental results

We also compared some details of the simulation results and experimental data: the durations of phases and the angles between the table and the board at the moment of phase changes. In general, the correspondence of the model and the experiment is quite satisfying. We did not expect precise correspondence because there are further facts that influence the motion, like the air resistance or radius of the table edge, that are not included in the model. Though, the character of the motion is described satisfyingly.

For the case of high friction, the difference between the model and experiment is quite big. We expect this to be an effect of energy losses while the grains of the sandpaper interact with the wooden board, however, precise understanding would require further study of the problem.

It can be seen that in our conditions the friction between the table and the board doesn't influence the angle of landing significantly. (It influences the details of the motions but their changes seem to compensate themselves in the final result.)

What does really matter is (expectedly) the moment of inertia J. A board with a small J (with two iron weights near the centre) gains during the fall a reasonably higher angular velocity than a plain board, the angular velocity of a board with big J (weights near the ends of the board) is lower.

Unluckily, if the board was a slice of bread, it would still land butter-side down regardless of the friction or the moment of inertia. To avoid this in some cases, we would have to use a higher (in case of small J) or smaller table (in case of big J).

7. Conclusions

Though the correspondence between predictions of the model and experimentally analyzed motion of falling board is not perfect due to further phenomena that are not taken into account generally the results are in good agreement and the influence of various factors is clearly seen.

When compared to previous studies, our approach is new in studying the effects of changing parameters of the motion (moment of inertia of the board, and friction). Innovative is also the idea of recognizing and separating the three phases of the motion that was performed in both model and experiment and used for their comparison. Our experimental method is more precise and both experiment and model were made using common or free software tools. There are further interesting problems to study, for example to examine the details of initial phases of the motion or to take into account the shape of the table edge in the model. These we would like to deal with in the future.

We think that the problem of falling bread slice might be extended into a quite interesting project or a lab for students, hopefully in two variants – at high school and university level.

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Lab Experiments as models of Real Situations. Modeling Strategy in Teaching Physics

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Abstract

School experiments can be seen as models of more complex, realistic situations. Students usually fail to see this relation. We suggest a strategy for guiding students to build a bridge between everyday phenomena and experiments performed in laboratories at school. An explicit case is presented in details with the game "bocce". Students of two classes were involved and the outcome of the project has been evaluated.

Models in physics instruction

Models have been playing an essential role in scientific research and in understanding nature. Therefore they are also crucial elements of science instructions at all levels. However, many students have difficulties to understand the concept of scientific models [1]. This also shows a deficit in the teaching of these concepts.

A unique definition of a model does not exist, but there seems to be general agreement that a model has – at least – the following attributes [2]:

- a model is a simplified version of an object or a process,
- it has predictive power,
- these predictions have limitations.

Although these points allow for a broad application, very often physics instruction focuses on theoretical and mathematical models [3].

Experiments have proven as very useful tools in teaching physics. Most of the time, these experiments are entities of their own to the students. The students do not see that they are models of more complex phenomena, and, moreover, the students do not see the purpose of this simplification process. In the following, we will present an approach where the transition from real situations to lab experiments, how and why it is done, should become more transparent to the students.

Modeling strategy

Starting points for the strategy are the following important features of physics teaching – student's interests, activity and knowledge.

Surveys of students all over the world, asking which part of physics is most interesting for them, come up with a similar answer – everyday physics, phenomena which are close to the students. [4]

In school physics, students' activities often include performing experiments, which has several positive attributes:

- They show physics as a natural science. The answer about the validity of a hypothesis has to be given by nature.
- They include a haptic component.
- Very often, students have to work in groups to perform an experiment.

Each student brings his/her own experiences of the real world into the classroom. Students construct their own knowledge, verifying, fighting, interacting and comparing their acquired experiences with the teacher's presentations and explanations. It is not easy for the teacher to know which kind of interpretations of the real world students have. But teaching which doesn't take care or doesn't start from the initial experiences of students is bound to be unsuccessful.

Having these arguments in mind we elaborated a strategy to reach the above mentioned goal – to build a link from reality to lab experiments.

- 1. The starting point has to be an appropriate choice of a **real situation**. It should attract the students' interest and it should be well suited with regard to experimental facilities. The situation can be such that the students are so familiar with it that they don't relate it to physics at all. They should act within these surroundings.
- 2. The teacher proposes **activities** inside the real situation. These include measurements, where all students have to participate actively. The students should become curious about what everyday objects can hide or how they could be used for explaining and understanding new concepts.
- 3. This very vivid activity has to be **reflected in the classroom**, where it is important that the students have enough time to analyze the data, to discuss their results and to connect them to their theoretical explanations. In this process the students can become aware that their data are not good enough or that the results don't match with theory.
- 4. The students should propose **lab experiments** in order to solve these open problems in the interpretation of the real situation. They should come up with clear suggestions of measurements and which parameters to vary.
- 5. The succession of and interaction between these processes should yield a **more profound understanding** of the phenomena, about the role of models and, maybe, even about the way of scientific research.





An example – the game bocce

Real situation

In Mediterranean countries one of the most popular game is "bocce". An expert was invited to describe a bocce field, to explain the rules of the game and to demonstrate how to play (Fig.2).

Figure 4: Explanation on the bocce field by an expert.



With the guidance of the expert, the students tried different techniques, they launched the balls, they rolled them in different ways etc. Finally, two teams played a game.

Activities

At the beginning of the second class in a secondary school in Slovenia (15-16 years old students) the students should "in general" know properties of uniform, accelerated, circular and parabolic motion. Dynamics is a more demanding topic, students usually have problems to understand the meaning of force, momentum and their (non)conservation, for example in collisions. The game bocce allows observing and discussing some of these components of kinematics and dynamics: linear and parabolic motion, dynamical friction, rolling and gliding, collision of balls of equal and different size.

The students were divided into four groups and they occupied the four corners of the bocce field. The teacher proposed and discussed with them the activities which they should perform:

- One group should study the deceleration of the balls. They should roll the balls with different initial velocities and measure distances and times (with meter stick and stopwatch).
- The second group worked on the law of dynamical friction. They again measured times and distances by varying masses and radii of the balls and using different surfaces (Fig. 3).

Figure 5: Movement of balls on different surfaces



- The third group made videos of parabolic throws. They should hit the small ball (balino) which was located at different distances.
- The fourth group investigated different collisions of balls. They again used videos for the analysis of the process.

Classroom

Before the reflections in the classroom, the students had to write reports of their activities, experiences and measurements. In general, it was possible for the students to connect their measurements and the results with the formulae they knew from school, i.e. they could interpret parameters more or less correctly.

- decelerated motion

The students calculated the negative acceleration of the balls out of their time and distance measurements.

- parabolic motion

The distances to the balino were 1 m, 2 m, 3 m, ..., 10 m. The students measured the initial angle from the videos and they calculated the speeds of the balls. The students concluded that for reaching a distance of 10 m a bocce player must run before launching.

- dynamical rolling friction

The students have measured the distances several balls needed to come to rest and also the time for this process. They calculated the value of (uniform) deceleration.

Using the Newton's second law and the law of dynamical rolling friction they could calculate the constant of dynamic rolling friction.

- collision

By measuring the distances and the time periods the students calculated the velocities of the balls. They considered four different types of collisions: A ball collides with a ball at rest, a ball collides with the balino at rest, a ball collides with a second ball moving in the same direction, and a ball collides with a second ball which moves in the opposite direction.

The students had no problems in interpreting their results with regard to decelerated and parabolic motion. They were very interested in dynamic rolling friction, in the dependence on mass and radius of the ball and they compared their results to examples of cars. But the students had many problems connecting their measurements with the laws of elastic collisions; the data simply did not fit.

Lab experiments

Out of the discussion about rolling friction and especially the discrepancy with regard to elastic collisions the idea for additional experiments came up. In particular, the students used different bodies (shapes) pushing them with the same velocities on different surfaces (Fig. 4). In order to have the same velocity they developed a special method, namely pushing the body with a stick. They also investigated collisions of various bodies on different surfaces.

Figure 6: Observing the rolling of a ball, a student explains the motion on the blackboard.



The students did not find that the reason for their mismatch in the elastic collision was their measurements of average velocity (using large distances) instead of the velocities close to the collision. They suggested intuitively that it has to be connected to friction and rolling. During the discussion the idea came up (guided by the teacher) to eliminate friction and rolling and

therefore to use an air track (Fig. 5). Although the students had problems with the experimental setup and the measurement, they were satisfied that they could verify the conservation of momentum.

Figure 7: Lab experiment with an air track



Gaining in understanding

In general, one can say that the connection of real experiments with the already known, or learned in this context, physical formulae developed a better understanding of the relevant parameters and also of their relation to each other.

The choice of lab experiments needed the impetus of the teacher. But then the students showed creativity in varying different parameters.

The students (especially the group with the collisions) also understood the purpose of the process of simplification - to eliminate friction, gliding instead of rolling bodies, a linear movement on the air track instead of motion in two dimensions.

Evaluation

The project was done with 15 students of the second class (15-16 years old) of the Ginnasio G. R. Carli Capodistria. After one month a questionnaire was given to the 15 students (group A) as well as to 5 students of the third class (16-17 years old) who knew the game bocce (group B - control group).

Both groups did well in explaining the motion of the ball. The greatest difference was whether a smaller (balino) or larger ball rolls for a longer distance. Group A interpreted the question by friction, group B had the concept of momentum in mind.

The requests to draw and quantify the situation of a ball coming to rest and of colliding balls was more problematic for both groups, they drew mainly realistic pictures with persons and balls without physical details.

We asked again which lab experiments resemble a bocce game. The answers were not satisfying (e.g. proposals of other games like billiard or to take smaller balls), showing that the students are not used to this kind of thinking – the support of the teacher is needed.

The majority of the students stated that the project "bocce" was amusing and helped them to better understand dynamic friction and elastic collision. On the other hand, the lab-experiment with the air track was regarded as too difficult by the majority of the students.

Conclusion

Real situations can be useful starting points for physical investigations. In the questionnaire the students expressed very clearly that the real situation helped them to understand the meaning of certain variables. The transition to "cleaner" experiments in the lab was very useful but it needed the guidance of the teacher. In conclusion, the strategy stated above is a possibility to motivate students, to link real situations with theoretical explanations using lab experiments as models, and finally to gain a better understanding of physical processes.

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An interpretative model to evaluate the thermal conductivity of the filament in a bulb lamp

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Abstract

Among simple electrical devices, the incandescent lamp is one of the most studied because of the various processes involved in its operation, depending on the electrical and thermal properties of the material of which is made its filament. For this reason, simple measurements of current and voltage allow several fertile analyses by means of interpretative models. In our previous works on this argument we used this device to characterize the electrical properties of the tungsten at high temperatures, in an operation mode of the lamp dominated by the emissive processes. In this work we present IV measurements executed in an isothermal environment, in the operation zone of the lamp in which the electrical conduction is still not ohmic, but the emissive processes are not relevant and the dominant heat exchange process is the thermal conductivity of the tungsten, by means of an interpretative model a la Fourier of the system, based on the analysis of energy fluxes in the filament.

Introduction

Numerous physical phenomena are involved in the operation of an incandescent lamp, depending on the basic properties of the material that constitutes its filament. For such a reason, many educational proposals, based on the study of the tension-current (V-I) characteristics of this electrical device, have been developed in the previous years (1-4). Anyway, these proposals are mostly aimed to investigate the processes involved in the lighting of the lamp, in which the emissive process dominates all the other thermal dissipation mechanisms. However, from a didactical point of view the operation of the lamp is interesting also at low (V-I), when the thermal conduction is the dominant process for the heat exchange. In this framework, we propose an activity based on experimental measurements and interpretative modeling, aimed to the evaluation of one of the physical properties of the filament, the thermal conductivity.

Energy fluxes balance in the lamp's filament

Let us consider a piece of a lamp's filament, with extremities at -X and +X in respect to the filament center, chosen as the origin of a coordinates axis x.

When a current I circulates in the filament, an incoming energy flux is generated by means of the Joule effect, with power $P_{Joule} = I^2 R$, where R is the resistance of the piece of filament, related to the resistivity ρ of the material of the filament by the relation

$$R = -x \int^X \rho / A \, dx$$
 [1]

Other energy fluxes derive by the heat exchanges with the closest other parts of the filament (conduction), with the gases present in the bulb (convection) or by means of emission processes; however, at low temperatures only the first process is significant. In a steady state, the power balance is given by

 $P_{\text{Joule}} + P_{\text{cond}}|_{x=X} + P_{\text{co}}$

$$P_{\text{oule}} + P_{\text{cond}}|_{x=X} + P_{\text{cond}}|_{x=-X} = 0$$

(there are two conduction contributions, because of the two extremities of the wire). The power exchanged by conduction can be evaluated by means of the Fourier's law or heat conduction

$$P_{cond} = K A \frac{dT}{dx}$$

where K is the thermal conductivity of the material and A the area of the section of the filament.

On supposing that the temperature field along the filament is symmetric in respect to its center, the power balance equation can be written as

$$I^{2}R + 2KA \left. \frac{dT}{dx} \right|_{x=X} = 0$$
[2]

On supposing to vary the length 2X of the piece of filament considered, relations 1 and 2 can be considered two equations that allow to explore the temperature field within the filament.

An approximation: uniform thermal and electrical conductivity

In order to solve eq. 2, the dependence of K and ρ on temperature must be known. At low circulating current, both the properties vary only slightly in the filament and an approximation of order 0 can be introduced by supposing that K and ρ are uniform in it.

Relations 1 and 2 become respectively

$$R = \langle \rho \rangle 2X/A \qquad [1']$$

$$I^{2} < \rho > 2X/A + 2 K A \left. \frac{dT}{dx} \right|_{x=X} = 0$$
 [2']

Equation 2' implies that the temperature field is quadratic in the coordinate x

$$f(x) = -\frac{1}{2} I^2 < \rho > x^2 / KA^2 + const$$

where *const*, the arbitrary integration constant, can be determined imposing that the temperature of the extremities of the filament is T_0 , the temperature of the environment. We obtain

$$T(x) = T_0 + \frac{1}{2} I^2 < \rho > ((L/2)^2 - x^2) / KA^2$$
[3]

where L is the total length of the filament.

We can use expression 3 to calculate the average value <T> of temperature in the filament $<T> = _{L/2}\int^{L/2} T(x) dx / L = T_0 + 1/12 I^2 <\rho> L^2 / KA^2 = T_0 + 1/12 P_{joule} L / KA$

With a liner approximation of the temperature dependence of the resistivity

$$<\rho> \cong \rho() \cong \rho_0 + \left. \frac{d\rho}{dT} \right|_{T=T0} (-T_0)$$

we obtain

$$\mathbf{R} = \mathbf{R}_0 + \left. \frac{dR}{dT} \right|_{T=T0} \mathbf{P}_{\text{Joule}} / \left(12 \mathbf{K} \, \mathbf{A} / \mathbf{L} \right)$$
[4]

Eq- 4 shows that, in this approximation, the resistance depends linearly on P_{joule} with a coefficient that depends on the thermal conduction K. For this reason, it can be used to experimentally evaluate the value of K, by means of (V-I) measurements.

Experimental setup and typical data results

We used a bicycle lamp (6V 2.4W) powered by the 1.5W function generator (FG) output of a ScienceWorkshop 750 Interface produced by Pasco.

The current I circulating in the lamp was automatically monitored by the FG output, while the difference of potential V was measured by means of a voltage probe, acquired by the interface.

The FG was setup in order to shape the voltage signal as a triangular wave, with a voltage change rate of 9. mV/s. This value is low enough to make sure that the curves I-V superimpose during the ramp up and the ramp down of the signal, a clear signature that the lamp operates in an almost steady state.

The temperature of the environment has been defined and measured by dipping the glass part of the bulb in a water bath at the temperature of 10.C.

Fig. 1 shows the dependence of the lamp resistance R as a function of the electrical power P_{joule} , as calculated by means of the I-V values acquired. A linear fit in the region (0 W $< P_{joule} < 0.011$ W), leading to the following estimate of R-P_{joule} correlation at low currents

$$R = 1.15 \Omega + 53. (\Omega/W) P_{joule}$$
 [5]



Fig.1 Resistance dependence on electrical power for the data acquired

Data Analysis

In order to evaluate the thermal conductivity K from data, by means of eq. 4, the two coefficients $\frac{dR}{dT}\Big|_{T=T0}$ and L/A must be estimated. This can be done by means of direct measurements, but for brevity one can evaluate them by using the relations

$$R = \rho L / A$$
 and $\frac{dR}{dT}\Big|_{T=T0} = \frac{d\rho}{dT}\Big|_{T=T0} L / A$

and tabled data for ρ and $\frac{d\rho}{dT}\Big|_{T=T0}$ for the material of the filament (tungsten) at the temperature T₀ = 10.C.

Interpolating the data from ref. (5)

$$\rho = 5.05 \ 10^{-8} \ \Omega m$$
, $\frac{d\rho}{dT}\Big|_{T=T0} = 2.3 \ 10^{-10} \ \Omega m/K$

we obtain

L/A = 2.28 10⁷ m⁻¹,
$$\frac{dR}{dT}\Big|_{T=T0}$$
 =5.2 10⁻³ Ω/K

and finally,

 $K = 1.86 \ 10^{-2} \ W/K \ m$ In good agreement with the value $K = 1.74 \ 10^{-2} \ W/K \ m$, reported in ref.(5) for tungsten at T=300K.

Conclusions

In this work, we propose an activity based on experimental measurements and interpretative modeling, aimed to the evaluation of one of the physical properties of the filament of an incandescence lamp, the thermal conductivity. The mathematical formalism involved makes it suitable for students at the last year of the secondary school and the experimental setup can be easily realized in a didactic laboratory.

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SUPERCOMET 2 – Modelling superconductivity

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Abstract

Physics education should deliver insight into modern physics. The aim of the EUproject SUPERCOMET 2 is the development of teaching material in order to introduce basic elements and applications of superconductivity in secondary schools. Partners from 15 European countries collaborate in SUPERCOMET 2. The cooperation with teachers at various schools is essential for the project since they are involved in all phases like development, adaptation and evaluation of the material.

Models of superconductivity can be built up on a macroscopic and microscopic scale. The first ones include experiments, the second ones can only be visualised by animations. Within SUPERCOMET 2, proposals of both kinds of models have been developed. They are collected on a CD-Rom which is available in 10 different languages.

A main focus of the German-speaking partners focuses on the development of handson kits for producing and investigating high-temperature superconductors. Suggestions are given for baking superconductors at schools as well as using them in easy-to-perform experiments. Furthermore, a new module about applications of superconductivity is in progress.

To facilitate the approaches, a teachers' guide has been translated into and adapted to German and Austrian requirements, and teacher seminars have been organised.

Superconductivity in school

In the past, a crisis in physics education has become obvious (Wilson & Warmbein, 2001). It is therefore necessary to think about new ways of teaching physics in school. One approach is to include contents of contemporary physics in the curricula [e.g. (Ostermann & Moreira, 2004)]. The discovery of superconductivity is one of the fundamental breakthroughs in the physics of the last century with consequences for everyday technologies (important applications in medicine, communication, energy and transportation) and also exciting possibilities for the future. Therefore it would be highly appropriate to think about and to make proposals for how to include the phenomena of superconductivity in the curricula. But it is also important to connect the "new" physics to the classical one (Ostermann & Moreira, 2004). Magnetism, electricity and thermodynamics are such links between classical physics and the modern topic superconductivity.

One possibility for including superconductivity in schools is with demonstration experiments with YBaCu superconductors [(Brandl, 1988), (Brüggemann, 1988), (Deger, 1988), (Deger, 1991), (Guarner & Sanchez, 1992), (Oberholz, 1989), (Schneider et al, 1991), (Shukor & Lee, 1998)] or even producing such pellets [(Brandl, 1988), (Deger & Luchner, 1988), (Deger, 1991), (Oberholz, 1989), (Zwittlinger, 2006)]. The critical temperature (T_c) of these superconductors is around 80K, which is high enough to use cheap liquid nitrogen (77K). So it is feasible to demonstrate phenomena such as levitation, the Meißner-Ochsenfeld-Effect and the vanishing resistance. Thus, students can observe the phenomena of superconductivity on a macroscopic level. In order to understand the behaviour of

superconductors on a microscopic scale, simulations and animations have proven to be very helpful tools. These two approaches of teaching superconductivity in schools are combined in the material developed in the SUPERCOMET 2 project.

The project

The EU-project SUPERCOMET 2 (SUPERCOnductivity Multimedia Educational Tool) is the follow-up project of the SUPERCOMET project. Within SUPERCOMET, material like self-contained e-modules about electricity, magnetism and superconductivity have been developed. They contain animations, texts, quiz games, a glossary of important terms plus a FAQ section, a search engine as well as some literature references and links to useful online resources. Also an accompanying teacher guide and an in-service teacher training seminar have been developed.

In SUPERCOMET 2, the partners from 15 European countries translated and adapted these contents to a large number of languages and national curricula. Furthermore they are in the process of developing material such as hands-on kits, additional simulations and a module about applications. Teacher seminars and testing in school to evaluate the material will complete the project.

Contributions of the German-speaking partners

One focus of the German-speaking partners lies in the development of a hands-on kit to demonstrate and perform experiments with superconductors in school. At the moment, the hands-on kit includes an instruction for baking superconductors in school and suggestions for easy-to-perform experiments. As mentioned above, it is possible to produce superconducting pellets with students in school. The recipe for baking such superconductors reads like one for a cake: take three different powders in well balanced quantities, mix them thoroughly, crush the mixture in an agate mortar and press tablets (Figs. 1, 2, 3)

Fig. 1. Utilities

Fig. 2. Mixture

Fig. 3. Press

After the tablets have been baked in a special oven (Figs. 4, 5) at 950°C for more than one day, they have to be cooled for two more days. Afterwards, the tablets have to be crushed, pressed and baked once again.

Fig. 4. Oven

Fig. 5. Regulation



After the baking process, the superconductors can be tested.

Exciting and easy-to-perform experiments to show the phenomena of superconductivity are the following:

If the sample is very small, it is better to use a toric magnet and let the cooled sample float above (Fig. 6). The sample will heat above T_c within a few seconds and then stop floating. Another possibility is to put a big self-made sample in liquid nitrogen. If a strong magnet floats above the sample, the sample passes the test of superconductivity (Fig. 7).

Fig. 6. A small sample floats on a magnet



Fig. 7. A magnet floats on a big sample



For the Meißner-Ochsenfeld-Effect the magnet is laid on the sample at room temperature. According to classic laws, no floating should happen as the magnetic field does not change any more. But after cooling the sample the magnet will float. This shows that superconductivity is more than perfect diamagnetism.

Furthermore one can build a magnetic track in different types (like a half pipe, a half pipe with a bump or a rectangular track) and let a cooled sample float above it (Fig. 8): One cuts stripes from magnetic rubber and forms a racing track. The YBaCu-sample that was cooled below T_c floats above some magnetic lines. The starting point of the track is a little higher than the rest of the track. The well-cooled sample will float for several seconds before the temperature rises above T_c .





Another focus of our contributions lies in planning and preparing a new module about applications of superconductivity. This can offer insights into modern technological

applications of physics and link theoretical knowledge to concrete use in industry, research and every day life. Explanations and illustrations for applications are categorized in six fields: Electric current with a minimum of energy wasting (transmission of electrical power, motors), generating huge magnet fields (e.g. Large Hadron Collider at CERN), magnetic levitation (e. g. maglev), producing magnetic fields for NMR (medical applications), measuring weak magnetic fields with SQUIDS (e.g. measuring the magnetic field produced by the currents due to neural activity in human brain) and accurate measurements of quantum voltage steps based on Josephson junctions.

Furthermore teacher seminars have been organized and first implementations in school have been started. In this connection the presented material was evaluated by focusing on the subject, the learning environment and the experiments. Some results of the students' feedback concerning the experiments and the learning environment are described below.

The interest in the experiments was clearly positive: on a 6 point scale the mean was 5.2, almost half of the students responded with the highest value of 6 (Fig. 9).





The interest in the material on the CD-Rom lays with regard to the average below the mean (3.5), as well as clearly below the interest in the experiments (Fig. 10). For interested students the program was better suited than for less interested. The differences between schools were minor; therefore, the shown results are rather related to the material than to the mode of application.



Figure 10: Interest in the learning program

Moreover, discussions with teachers have indicated a need for an extended teacher guide that is currently being developed.

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Modeling Killed the Lecture Demonstration – Are Demonstrations Dead? Modeling and Demonstrations in Research-Based Classes

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Abstract

Lecture demonstrations are common in physics teaching, yet a survey of the physics education research literature indicates a deficit of research into their effect on student learning. Even as demonstrations are included with newer modeling tools in researchbased classes, the research often does not test them effectively. We explore underutilized techniques for effectively integrating demonstrations with modeling tools. The experience with the PER group at University of Colorado, Boulder is reviewed. New web resources for lecture demonstrations are described, including databases, ordering tools, bibliography, and the Global Demo Web Spider. As essential as modeling is, demonstrations motivate successful models.

Introduction

This paper takes its title from *Video Killed the Radio Star*, a <u>1980s New Wave</u> song (released in <u>1979</u>) by the British group <u>The Buggles</u> that celebrates the <u>golden days of radio</u>. There is a 2000 parody of *Video Killed the Radio Star*, known as *Internet Killed the Video Star*.

The thesis of this paper is that the use of modeling in physics teaching has eliminated the use of lecture demonstrations. The title, "Modeling Killed the Lecture Demonstration", is intended to draw attention, and in an important sense, it is a true thesis. We will examine this in more detail. First however, there are exceptions to this thesis. The best physics instructors see the essential importance of real life demonstrations of the principles of physics in lecture. For an example, we need look no farther than one of the plenary speakers for this conference, Ron Thornton. Thornton and Sokolof (1997, 1998) have skillfully used modeling in their radically new Real Time Physics curriculum; yet they have also integrated lecture demonstrations in an effective way.

For the purposes of this paper, modeling is certainly not referred to in its general sense. In its most general sense, demonstrations themselves are a form of modeling. Nevertheless, for the purposes of this paper, practically all of the new teaching techniques can be thought of as "modeling". Anything which crowds out lecture demonstrations in the classroom experience will be lumped together in the "modeling" category. Specifically, technology-aided modeling is the subject of this paper. Examples are computer applications residing on classroom computers, use of websites in-class, and animated simulations, for instance, Java applets.

Lecture demonstrations are demonstrations of the phenomena of physics performed during lecture using everyday objects, toys, specially designed apparatus or general research equipment and instruments.

This paper will focus on the physics classroom experience at the University of Colorado over the last fifteen years or so.

Physics 2000 http://www.colorado.edu/physics/2000/

Beginning in 1997, Martin Goldman, a plasma research physicist at the University of Colorado, Boulder, began developing a set of Java web applets to enable introductory students to learn the principles of modern physics. The applets were specifically designed to be used on a "stand-alone" basis, so non-traditional students, not necessarily enrolled in any school, could be equally successful at learning as traditional students using the applets. Applet development was sponsored by the US National Science Foundation and the state of Colorado, as well as the University of Colorado, which provided the budget to have professional programming specialists write the Java code. Goldman's advisory team

consisted of some of the top research scientists at the University, including an atomic physicist named Carl Wieman.

PhET http://phet.colorado.edu/

In 2001 Professor Carl Wieman, along with another of our colleagues, Professor Eric Cornell, won the Nobel Prize in physics for their first demonstration of Bose-Einstein condensation. Within a year, Wieman began withdrawing from the research in his atomic physics laboratories, and began focusing instead on research in teaching physics to introductory, university level non-science major students. His first efforts incorporated the Thornton & Sokolov RealTime Physics curriculum (Thornton and Sokolof, 1997, 1998); he soon began using pre- and post- testing to evaluate student learning outcomes. Wieman found this curriculum too cumbersome for his tastes.

At this point, he began increasingly focusing on the use of Java applets in lectures – the same sorts of applets he had been involved with in Professor Goldman's Physics 2000 project. His status as Nobel laureate brought in grants which again have provided a substantial budget for hiring programming specialists to create the finest applets possible while his team of research physicists ensures the accuracy of the physics. He has assembled one of the largest and newest teams of physics education research specialists anywhere in the world, called PhET (Physics Eduaction Technology), which is now developing many new tools and exploring many new areas (Perkins et al, 2006).

Wieman and his team have recently published research results (Finkelstein et al, 2006, Keller et al, 2006, Perkins et al, 2004, 2006) indicating students had better learning outcomes from being presented with a Java applet in class than from seeing an actual physical demonstration of the principle. They have repeated this conclusion, that applets can be a better learning tool than demonstrations, in other articles (Wieman & Perkins, 2005, 2006).

This conclusion, however, is based on extremely limited published results and has not yet been replicated elsewhere in the literature. Comparing their in-class presentation of demonstrations and applets suggests serious reservations about their conclusions. While the researchers optimize every detail of applets presentations, the same is not the case for their demonstrations.

Data on only two comparisons of applets and demonstrations has been published (Finkelstein et al, 2006, Keller et al, 2006, Perkins et al, 2004, 2006). One of these two is for the topic of standing waves on a string. Demonstrations designed for this topic are common in secondary and college classrooms and are commercially available (Pasco Scientific item WA9857) as well as easily fabricated from readily-available materials (http://www.arborsci.com/detail.asp x?ID=594). The researchers specifically had available a lecture hall-scale motor-driven standing waves on a rope, with precisely variable frequency and tension (http://physicslearn ing.colorado.edu/website_new/common/ViewDemonstration.asp?DemoCode=3B22.10). A stroboscope (General Radio Strobotac 1531) was available to slow the apparent wave speed and observe individual segments of the string oscillating up and down.

Rather than choosing such a demonstration with similar features to their applet, the researchers chose to use hand-driven vinyl tubing, typically used to show traveling waves and pulses (http://physicslearning.colorado.edu/website_new/common/ViewDemonstration.asp? DemoCode=3B10.10). Yet their articles describe the precise control of variables in the PhET applet as one of their advantages over demonstration. Again, the applet's ability to slow the apparent wave speed and observe individual segments of the string oscillating up and down is singled out in the articles, ignoring similar capabilities for the demonstration.

The other published comparison, for electrical circuits (Finkelstein et al, 2006, Keller et al, 2006, Perkins et al, 2004, 2006), again used equipment for the demonstration not optimized or presented with the same preparation and care as that given to the PhET applet. Nevertheless, in the final analysis, they concur (Finkelstein et al, 2006) that "an optimal educational experience will involve complementary and synergistic uses of traditional resources, and these new high tech tools".

Effective Lecture Demonstrations

While traditional lecture demonstrations are certainly not an effective learning technique for students, if we completely eliminate contact with the actual, real physical world from our classrooms, we are not teaching physics. The published research on the use of demonstrations in the classroom has not effectively applied the principles of physics education research to the integration of the demonstrations themselves into the classroom learning experience.

Traditionally, a physics lecturer might introduce a concept, develop it mathematically, discuss examples, solve problems, and then perform a demonstration with no discussion. To be an effective learning tool, demonstrations should be presented in the research-based context Thornton and Sokolov (1997, 1998) have discussed:

Concept challenge

Present the physical objects, equipment, or instruments to the students and ask what will happen when the experiment is performed.

Collaborative small group discussion

The students develop an informal hypothesis and predictions in groups of three or four students each. Each group works towards a consensus view. The discussion is facilitated by mentors consisting of the instructor and assistants.

Individual investment

Each student expresses their prediction independently using a classroom response technique such as colored cards or an electronic feedback system.

Demonstration

Now the demonstration is performed. The best demonstrations are counterintuitive to the average student's preconceptions. The unexpected result presents an opportunity for the student to reevaluate their preconceptions and consider a more sophisticated, physically accurate concept of the physical principle.

Reinvestment

Through discussion, the collaborative small groups have an opportunity to integrate the more accurate physical picture into their group understanding, reinforcing the more accurate concept for each of the individuals.

New tools at the University of Colorado

Lecture Demonstration Web Database

This website, <u>http://physicslearning.colorado.edu</u>, contains an interactive database of demonstrations and audio-video items available for lecturers. It includes a table of contents, search engine, descriptions, photographs, videos, and animations.

Instructor web accounts

Each instructor has a web account they can logon to which allows them to reserve items for a specific class. The web database recognizes each instructor and already knows all the courses the instructor is teaching, the days of the week and time of day of each course. The database checks for reservation conflicts to prevent instructors from making conflicting reservations for the same equipment at the same time. Requests are compiled and displayed in chronological order for staff to use in preparing items for class.

Demonstrations Sorted by Course and Semester

<u>http://physicslearning.colorado.edu/website_new/common/ldl_democourseList.asp</u> The database makes it possible to store demonstration use information so new instructors can examine what has been used in the past for each day of each course.

PIRA Bibliography of Physics Lecture Demonstrations http://physicslearning.colorado.edu/PiraHome1.asp The Digital Classification Scheme committee of the Physics Instructional Resource Association has developed a scheme specifically for classifying physics lecture demonstrations. The committee then used this scheme to create a bibliography of all references in the published physics literature to every lecture demonstration.

The Colorado website is home to the world's only interactive web version of this bibliography. The site has live links to the best available web link for each bibliographic literature source.

Global Demo Web Spider

http://physicslearning.colorado.edu:9999/vestris/QuerySp.html

This site hosts the world's only two web spiders to exclusively crawl all the world's 56 physics lecture demonstration websites regularly and compile a searchable index of the sites.

Automated Homework System

<u>http://www.colorado.edu/physics/CAPA/Cindex.html</u> The University of Colorado is using CAPA, a web-based student homework system.

Student Response System

http://www.colorado.edu/physics/phys1120/phys1120 fa06/

Currently an infrared/computer based transmitter/receiver system is used for student feedback in the classroom. This system was initiated by the physics department and has been adopted cross campus in more than forty classrooms and ten departments. The current system will be replaced with a radio-frequency system for the 2007 school year.

Conclusion

As essential as modeling is, demonstrations motivate successful models. Effective demonstrations require challenging students' preconceptions, collaborative, small-group discussion, and reinforcement of the new, more physically-based concept. The University of Colorado, Boulder Department of Physics has developed new tools to facilitate the use of physics lecture demonstrations, including a web database, instructor web accounts, the web-interactive PIRA Bibliography of Physics Lecture Demonstrations, and the Global Demo Web Spider. Additional research-based technology in use includes web-based homework systems and student response systems.

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Primary School Physics

"Let's shine light on the matter": A physics show for primary school

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Abstract

We have developed a Physics Show for Primary Schools (age 8-11) in which three physicists perform many fascinating experiments in the context and with the structure of a real play. The show deals with the matter and its states, and with the light and its behaviors when it interacts with the matter. Themes as state changing, reflection, refraction, diffusion, colors of light, and also infrared vision and polarization of light, are tackled with the aid of scientific instrumentation and of some custom made devices in an informal learning contest. The show has been realized in collaboration with a theatre company specialized for children, and in its first two years of life it has reached about 15.000 students in Italy.

We present here the results of a study on the effects of the show on children. They seem to indicate that the show leaves a lasting mark in kids, and is probably effective in changing the perception of physics, and the knowledge of the work of a physicist.

Introduction

The Physics Department of the University of Milan, in collaboration with a theatre company specialized for children, has developed a project of Physics diffusion addressed to kids in the age range 8-11. "Let's shine light on the matter" [1] is a show in which three scientists perform exciting experiments on stage, dealing with the light, the matter and the many ways light and matter can interact. The show lasts approximately 45 minutes and it is followed by a debate between the children and the scientists, that takes about half an hour. It has been presented on invitation in many successful Italian events for the popularization of science [2]. The unexpected success and the large number of young students that have attended the show in its first two years of life (almost 15.000 kids in Italy), have stimulated us to find out if the show has any effect on the children science perception.

In this paper we present the results of a study in which we have tried to determine whether and how the vision of the show has affected the children perception of science and of scientists.

The Project

The image of the physicist among people that doesn't work in the field is extremely far from reality, and most people know almost nothing about what a scientist or a physicist does in his work [3-8]. Most people have a contradictory behavior: from one side they rely completely on science but, on the other, they show a crisis of confidence towards scientists' work [9]. This means that, although only few go to study Science, there is an increasing demand of scientific knowledge coming from common people: the open day for the 50° birthday of CERN brought to Geneva more 30.000 people and similar "assaults" of families can be seen, for instance, in every open day of the INFN-LNGS (National Laboratory of Gran Sasso-Italy) and in most of the Science Centers in Europe and in the USA, as well as in the Science Festival of Genova and BergamoScienza [2]. An Italian survey made in 2004 by IRPPA-CNR showed that *New Technologies* and *Scientific Discoveries* have the highest "Interest Level" among young people (besides Music that has a share of 52.9%), with scores of 32.1% and 24.5% respectively (percentage not normalized) [10], and that nearly everybody in Italy thinks that research should have more financial support. In Italy, to comply with this demand of information, there is the growing of more and more popular science magazines, but, on the other hand, Physics is one the most disliked subject (more than Mathematics and Chemistry) for most of high-school students [11].

A fact that is well known is that at some time during school education, something happens that moves away the "good" feelings about science: going from primary school to secondary school indifference and fear are generally increasing. This is why we chose to address our efforts to an audience of children, as they are curious, fond of learning, and hopefully still free of prejudices.

What we intended to do was to awake children curiosity and interest in science and to give birth to a fascination towards Physics. Moreover, we wanted children to meet real scientists performing the experiments in the hope that the scientists might act as positive real models for some of them and also

help in winning their (future?) diffidence in science... as a child told his mother with excitement "there were real living physicists there!"

The Show

We projected a show that is completely different from either a lesson or any school activity. It is a theatre show in which three scientists perform many experiments in a "laboratory" that is very similar to a real Physics one. We have impersonate some of the more enjoying stereotypes of the scientists [3-8], to gain the children trust, as it is well known that upper primary age children are delighted by some exaggerated characters that seem "tailor-made" for them [5]. Our scientists wear white lab coats, two of them wear eyeglasses, and one has beards; in the lab there are various symbols of research and relevant formulae on blackboards. By contrast, we have deliberately chosen to avoid some of the negative stereotypes [7,8] as for example that scientists work alone or that they are males (one of them is a woman).

Particular care has been taken for choosing the words and make the script neither trivial nor difficult.

The show deals with the following topics: states of matter and changes of state, reflections and mirrors, total reflection, refraction, dependence of the refractive index on temperature; light scattering by small particles, additive and subtractive synthesis of colors; dispersion of light; night vision with infrared radiation, transparency of pigments in infrared, and polarization. In the show the physicists-actors play 32 experiments introducing these subjects in an unconventional way.

For instance, after presenting the three states of matter (solid, liquid, and gas), the physicists introduce foams and gels and ..."Silly-Putty" [13] a viscoelastic material, made of silicone based polymer, that is highly elastic, exhibits high bounce, can be easily molded, and cannot hold it shape while at rest, for a long time (Fig. 1). When facing light phenomena, after introducing light and colors, one of the scientists is found in the darkness with an infrared camera (780-1100 nm) and another one discovers the curious behavior of painting pigments that are almost all transparent in the NIR region.

Fig. 1 The ball of Silly-Putty changes shape, and stretches out as a chewing gum





Research and Methods

To study the effect of the show on children we have tried to answer the following research questions:

Q1 Physics and the work of physicists. Has the perception been changed by the vision of the show? Q2 Appreciation of the show. How did children and their teachers judge the show? As it impressed them?

Q3 Memories. What did children retain of the show? Which experiments did most impress children?

Q4 Suggestions. What suggestions can be given for the future of the show?

To answer these questions we analyzed:

- 1. Questionnaires answered by teachers accompanying the classes, concerning the effects of the show in terms of class discussion and didactic aid.
- 2. Interviews to the children in their schools, conducted with the help of one of us (G. C.) that is a pedagogist. To avoid biases, school principals, teachers and children were not made aware in advance that the interviews was related to the show.
- 3. Questions made by children at the end of the show and drawings sent us by children.

Results

1- We analyzed 50 questionnaires answered by teachers, they put in evidence some points.

In every class the children have spoken about the show in the week following the vision, without any

suggestion coming from the teachers; and in 36% of the classes the children have spoken of the show

among them. The teachers have judged that for 98% of the children the interest was "good or high", and

for 89% the comprehension was "good or high".

The opinion of the teachers about the show was almost unanimous: all of them found it useful as a didactic aid and noticed some improvements in the knowledge of physics of the children. Finally 98% considered that the show has connections with the school program.

2- The interviews to the children, lasted between 30 and 60 minutes, had the principal aim of evaluating their memories and changes in the perception of science. To do this a comparison with a set of "control" classes which have not seen the show has been necessary. The number of interviewed classes has been 57 (about 1100 children), 26 of which have seen the show this year, 13 which have seen the show last year and 17 which have not seen the show.

The result was that all the classes remembered the show. 68% of those that have seen the show this year and 46% of those that have seen the show last year remembered it spontaneously. The percentage grows to 80% for both, if a little hint is given (i.e. a pen laser used in the show, a picture of a rainbow and so on) while only for 20% of the classes an explicit connection to the show has been necessary to have e recollection.

For what concerns the Perception of Physics and of the Physicist work we can look at the following table:

		Show attended in 2006	Show attended in 2005	Control classes
Do children know what	Yes, making explicit connection to the show	70 %	27 %	
a physicist works about?	Yes, with no explicit connection to the show	15 %	64 %	20 %
	no	15 %	9 %	80 %
Do children make	Yes, he/she works on matter	57 %	33 %	
connections between the work of a physicist and the show?	Yes, he/she works on light	21 %	67 %	
	Yes, he/she works on colors	21 %	0 %	

Tab: Perception of Physics in Children after the show

3- We have analyzed the 188 question asked by children at the end of the 13 shows performed in an auditorium in our University. We stress that the questions have been always pertinent, all about Physics (never about Chemistry, Biology or whatsoever...). They can be divided into two categories: questions about the experiments of the show, and questions starting with: "what happens if...". We analyzed 497 drawing on more than 1000 received. They contain many details reveling a great attention to physical phenomena. In this paper we only refer to the recurrence of the experiments All but 1 of the 32 experiments have been remembered by children and the subject partition of the show (1/3 about matter and 2/3 about light) has been recovered in the drawings and in recollections of the children during the interviews. The experiment never remembered is about Rayleigh scattering by small particles suspended in water. We are working to modify it.

Conclusion and comments

With these results in mind we can answer the 4 questions we put above.

- Q1 from the interviews we have observed a significant change in the perception of physics and in the knowledge of the work of a physicist (90% of children who have seen the show compared with the 20% of those that have not).
- Q2 the great enthusiasm of the children at the end of the show and the large amount of pertinent questions are clear signs of their appreciation. The same enthusiasm has been observed during classroom interviews and from drawings and mails we received. The appreciation of teachers has been by far more than expected. We have received so many requests from the schools that we have not been able to satisfy all of them.
- Q3 from the interviews we observe that recollections of the children are very rich and precise; that most children have spontaneously spoken about the show starting from generic arguments and that 90% of the classes, which have seen the show, know what physics work is about, while this percentage goes to only 20% for the classes which have not seen the show. From the drawings we can say that the experiments which impressed children the most have been those with laser light and those with liquid nitrogen.

• Q4 for what concerns question 4, the thing teachers asked the most, is the possibility of a collaborative work with us especially to delineate school uses of the show.

All this has been achieved by no means through a lesson but a careful study of a theatrical language and a show full of amusement and joy.

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The basic models in the experimental work of student-teachers of primary school

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Abstract

This work, issued from an ongoing collaboration between the researchers in Physics education of the Universities of Udine and Modena-Reggio Emilia, focuses on an educational and training process which allows to bridge experimental work and formal thinking, thus providing professionalizing bases to teachers to-be. This process was performed within the course in "Design of Educational Experiments" which is a part of the degree course in Primary Education, placing the student-teachers in a critical position by proposing project activities which implied reflection not only on the operational elements of the organization of simple experimental activities for children, but also - and mainly - on the role of such activities in science education. The students were asked to illustrate the models underlying specific sets of experimental activities and to discuss their reflections upon these models. For the design and reflection phases the students could benefit from the opportunity to design activities using specific materials, as well as sufficient time for discussion through a web-based environment supplying web-forums and a cooperative writing tool.

The role of models in teaching and in scientific knowledge

A scientific model is a type of theoretical construct that, together with the other components of a theory, guides the observation of reality, the posing of a problem, and all the other characteristic strategies of scientific research.

Physics assigns a central role to the model as an interpretative instrument in the behavior of systems (Hestenes, 1995; Grosslight et al., 1991), therefore modeling should be regarded as a main methodological way of teaching and learning the discipline (Grosslight et al., 1991; Clement 2000; Snir et al., 2003).

Models are matter of interest for the research in science education because their mastery leads to increased teaching competences, and it becomes mandatory their inclusion in the curriculum of teachers of physics education.

Literature shows as abstract model instruction is not effective in terms of significant learning, in spite of learning models in a context of interpretation of experimental activities (Hestenes, 1995; Grosslight et al., 1991). In order to provide basic science training to primary school teachers it is necessary to promote the use of physical models as a methodology of approaching open problems.

This can provide teachers with the necessary competence to design and carry out activities of experimental exploration, as well as to propose to children model-oriented and model-conducted didactical activities.

The cognitive demands of modeling on non-experts (the students) are not the same as on experts (Harrison, Treagust, 2000; Snyder 2000) and to better achieve the goal of student-teachers training, due to their weak science grounding, it is necessary to improve their competence on a limited number of basic models and model elements, though ensuring good scientific foundation

Research question

Assuming that

- teaching models is more effective in a context of interpretation of experimental activities,
- the personal involvement of the learner with the learning subject is essential to raise competence on the subject,
- a teacher's ability to manage scientific knowledge is related to his/her skill in the use of models,

we mean to investigate the basic models in the experimental work of student-teachers of primary school, focusing on model-related cognitive structures and model elements emerging from the students' work. With *model elements* we mean some features which are common to the various rigorous formulations of what a model is. In the Table 1 we draw up the list of model elements considered in this work.

- Table 1. Model elements
- 1. Identification of the physical quantities relevant for the study of a phenomenon
- 2. Finding *relations* between the relevant physical quantities
- 3. *Explanation* of a phenomenon, going beyond a mere description and using the physical quantities and the relations among them
- 4. Reference *to theoretical elements*
- 5. Correlation of phenomena among different contexts

Work context and operational phases

Team: teachers of Faculties of Education, University of Udine and University of Modena-Reggio Emilia Subjects of the intervention: 39 students of the course of *Design of Educational Experiences* (following a course of Physics Fundamentals) of the degree in Primary Education, carried out in both Universities at the same time.

Activities: after 8 hours of exploration activity at the GEI (Games, Experiments, Ideas) exhibition in Udine (Michelini, 2000), the students split into several mixed workgroups, chose a problem from those proposed in the exhibition and followed the subsequent activities:

- designing and executing an experimental activity
- carrying out a common reflection and discussion through a web-forum
- carrying out a didactical design activity

Support tools: a web-based environment offering different discussion and collaboration tools.

Here we consider the student contributions concerning the experimental problems reported in Table 2.

Table 2. Experimental problems
EP1. Calibration of a dynamometer
EP2. Elongation of an elastic band
EP3. Series and parallel springs
EP4. Equilibrium of a rigid rod
EP5. Buoyancy of solids into liquid
EP6. Fall of a ball from a ramp
EP7. Thermal interaction between equal masses of water
EP8. Lens and images formation

Results: exploration activity

During the in-presence exploration activity the student filled a form based on the prediction-experimentcomparison cycle. The form aided the student in designing and carrying out the experimental exploration, according to the open items of Table 3.

Table 3. Form Items			
IT1. Problem			
IT2. Theoretical aspects and hypotheses for the experiment			
IT3. Materials and how to assemble them (scheme)			
IT4. Phases of the experiment (<i>layout</i>)			
IT5. Identification of the data to be collected			
IT6. Predictions/Expectations (questions that the experiment means to answer)			
IT7. Data and their representations (tables, graphs, charts,)			
IT8. Notes relevant to the experiment execution (actual modalities of execution, difficulties)			
IT9. Data analysis			
IT10. Discussion of the data			
IT11. Comparison of data to predictions/expectations			
IT12. Concluding remarks			

The filled forms are analyzed by extracting a significant set of items (IT1, IT2, IT6, IT10, IT12) and analyzing them from two points of view, according to:

- 1. a grid of criteria, specific for each item, open to integration with further aspects emerging from the reading of the data (Niedderer, Deylitz, 1999).
- 2. the set of model elements

Item analysis

The elements emerged from the analysis of the selected items are reported in the tables 4-8. A brief comment follows each item.

Table 4. ITEM 1: Problem			
Element	%	detail	number
Questions	(30%)	targeted	6
		general	7
report	(21%)	of a phenomenological behavior	8
Study	(41%)	of relation	2
		of experimental conditions	
		of comparison with a known situation	2
		of the consequences of a certain action	6
		general	4
Procedure	(8%)	to follow to get a result	3
		by trial and error to get a result	2

In the case of already studied phenomena, the students pose the problem mostly in terms of a search for relations. In the case of new phenomena, they tend to: ask open questions; propose observation activities.

Table 5. ITEM 2: Theoretical aspects and hypotheses for theexperiment			
Partially	6		
completely	14		
relation	12		
mere observation of phenomena	8		
mere experimental conditions	2		

In 51% of cases the students succeed in identifying the theoretical bases underlying the experiments, either totally (36%) or partially (15%). In the particular case of systems of springs, they do not try to find the correlation between the properties of the system and those of its components.

Table 6. ITEM 3: Predictions/Expectations			
A mathematical relation is expected	16		
Predictions are made according to experience (empirical)	9		
No predictions are made but questions are asked	14 (10 descriptive; 4 explicative)		

The students expect proportionality relations (direct or inverse) in 41% of cases, whenever they deal with situations referable to known notions. Similarly to the case of the item "Problem", in the experiments EP4, EP5, EP7, they just tend to put questions without providing any hypothetical answer, or they make empirical predictions based on actual experience.

Table 7. ITEM 4: Data discussion			
Regularities are identified	27		
Comments are made on uncertainties and errors	5		
A system is divided into subsystems or considered as an entity interacting with the environment	7		
An attempt to explain the phenomenon is performed	3		

In 75% of cases the students succeed in identifying regularities/relations in both known and not known systems. In the EP1-2-3 experiments they succeed in recognizing formal relation between data and stressing the issue of errors. Therefore they recognize the irrelevant elements of the phenomenology and identify the basic ones by means of a mathematical law.

As regards the EP4 experiment, whose theoretical assumptions were not known, all of the students identified the rule of the equivalence of the product of the weight of the two arms of a rod and the distance between them. Some students generalize this principle for masses attached in several points.

Very few students (8%) try to provide explanations in this phase.

Table 8. ITEM 5: Concluding remarks	
Relations of proportionality are reported	25
Description only	24
Interpretation	6
Generalization of the observed phenomenon	18

Search for relations is present in 76% of cases, as has already been pointed out in the section relevant to discussion. There is a tendency to describe a phenomenon (73%) rather than explaining the causes of a behavior (18%) in terms of forces or of balancing of homogeneous physical quantities. In the specific case of springs (EP1, EP3) there is a greater tendency to description. The direct proportionality between elongation and weight distracts the students' attention from the recognition of the elastic force balancing the load. Different ambits should be considered, as regards generalization (55% in all): a specific aspect; a law of physics; a single phenomenon to a whole class of systems.

In Table 9 model elements are correlated with corresponding items results presented previously.

Table 9. Search for model elements and corresponding items						
	Problem	Theoretical assumptions	Predictions Expectations	Identification of data to be collected	Discussion	Concluding remarks
Identif. of all relevant quant	38%			100%		
Relation between quant		31%	41%		75%	76%
Describing phenomenon		21%	67%		94%	73%
Explaining phenomenon		36%	10%		8%	18%
Theoretical elements		51%				
Contexts correlation						75%

In all cases the students succeed in identifying relevant physical quantities. A marked tendency to search for and recognize proportionality relations between the relevant variables is evidenced. Students however show greater propensity to mere description of a phenomenon, without going deeper into the study of the agents underlying their observations. Significant is the tendency to extend an observed behavior to phenomena in different contexts.

Results: Web-forums

The students were asked to discuss in web-forums about the role of models in their experimental activity. The intervention in forum were analyzed from two points of view:

- 1. Statistical: percentage of words contained in the sentences ascribable to a particular model element
- 2. Qualitative: contents of the students contributions

Table 8 resume the statistical analysis.

Table 8. Statistical analysis			
Relations between quantities	15%		
Description of the phenomenon	12%		
Interpretation of the phenomenon	8%		
Presence of theoretical elements	18%		
Relation between a local phenomenon and its generalization	7%		
Identification and description of the model	40%		

In proportion to the case of the previous experimental activity, we can appreciate a remarkable increase in the students' tendency to provide explanations rather than mere descriptions of the observed phenomena. This indicates the relevant role of the web-forum discussions for organizing and raising awareness of the cognitive processes brought on by the activity, and for spreading and homogenize knowledge.

The qualitative analysis of student's contributions on models was carried out according to three main categories:

C1. Relation between models and phases of the methodological layout activity

C2. Influence of models on the approach to reality

C3. Properties of physical models.

Bout category C1, from the students contributions emerges an explicit multidimensional awareness of the importance and usefulness of model in every phases of the methodological layout activity.

For instance, students declare that the physical model: enables to "perform a clearer methodological layout of the experiment", "a more reliable collection and processing of data and a more precise comparison between the expectations [...] and the results"; is "a starting point for the formulation of new hypotheses".

Moreover having in mind a model, one is guided in carrying out and designing an experiment: - in the EP7 experiment, the discrepancy of 1 °C between theoretical model expectation and experimental results can be explained "thanks to the physical model: the result is different because the system used for the experiment was not an ideal insulated system".

- reference models (i.e. "uniformly accelerated" and "uniform" motion) and direct experience (i.e. "bidimensional motion") allow "to have known that it's possible to separate the two kinds of motion and analyze them independently".

Previous sentences also clarify, with reference to category C2, how some students approach a real situation using models.

The principal model properties (C3) indicated are:

- "bringing a real system and its evolution onto an abstract level, which can nonetheless be translated into mathematical form",
- helping "us to substitute in our minds the real object being observed with its conceptual representation", with "a sort of ideal experiment" performed with no "external interaction" or "inaccuracies".
- "a representation of a phenomenon", "distinct from the phenomenon itself".

Conclusion remarks

Designing and carrying out an experimental exploration promote for student-teachers a background of points/knots that web-forum discussion contributes to transform into ability to internalize and use the following model elements:

- Identification of the quantities relevant for the description and the experimental analysis of a phenomenon
- Deduction of relations among these quantities and identification of the irrelevant items
- Recognition of the similarities of phenomena among various and different contexts

As a result of the discussion in the web-forum we notice the following points:

- the explanation of the phenomena arises from descriptive to interpretative level
- students improve their ability to discuss in term of meaning and usefulness of models
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The evolution of direct current models

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Introduction

The problem of the models attributed by students to the direct current has a long history. Its investigation has been carried out since the eighties, and was repeated by many authors (Driver et al. 1885; Driver, et al. 1994; Borges & Gilbert 1999; Stockmakler & Treagust 1996). Four models where mainly identified in these investigations:



Figure 1. Unipolar model



- The unipolar model 1.
- 2. The clashing current model
- The unidirectional 3. decreasing (non conserved) direct current
- 4. unidirectional The conserved direct current.

It appears that the unipolar model (Fig.1) is mainly held by those children who do not have any organized knowledge about electricity. This model of spontaneous knowledge incorporates the notions of supplier and consumer. The supplier is the battery and the consumer is the bulb. As long as the bulb is connected to the battery it gives light

through an agent called 'electricity' (sometimes 'energy'). According to this model current can flow in an open circuit and the current is not conserved.

The clashing current model (Fig. 2) is also spontaneous. In it the current symmetrically initiates from both poles of the battery. Both currents clash in the bulb and light is created. Current is apparently not conserved.

In the *unidirectional current* model current leaves one pole of the battery and goes through

the whole circuit entering the other pole of the battery. Current can be conserved but there are pupils who do not accept this idea. They



Figure 3. Unidirectional model-1



Figure 4. Unidirectional model-2

suggest that current is consumed along the circuit and gradually decreases (Fig. 3).

The *conserved unidirectional current* model is taught by teachers (Fig. 4). In it the current flows in one direction. It starts from one pole of the battery, flows through the whole electric circuit, ending at the opposite pole. The current is conserved, that is, its intensity remains the same along the entire circuit.

This research suggests new aspects of this domain which we are going to address and discuss in this paper. These aspects mostly concern the way the pupils we investigated changed their views regarding the direct current models.

Method

Population and sample

We comprised our sample of participants from the Arabic speaking (Muslim) population living in a small town. For the purpose of the study we addressed three groups of participants whose knowledge should reflect certain dynamics of the ideas of the subjects, as shared by the relevant population of pupils and their teachers. The groups were as follows:

- 1. 40 pupils of fourth grade, aged nine.
- 2. 40 pupils of sixth grade, aged eleven.
- 3. 20 teachers teaching at the same school. The teachers were elementary school teachers with secondary school matriculation and four years of education in a teacher college.

Tools

We used a questionnaire incorporating ten open questions (Azaiza et al. 2006). Five questions asked for the ways people account for several natural phenomena. Other two questions addressed descriptions of electrostatic experiments common in introductory teaching of electricity. In choosing these questions we intended to find out how the participants' explanations considered the phenomena, whether and to what extent they relate them to electricity. A special question was asked about electricity trying to infer the images associated by the subjects to this topic. Two questions were aimed to check the models by which our subjects account for the direct current in a simple electrical circuit with one and two bulbs in series.

Results

The models of current held

Here we consider our data solely in respect with the models of direct current as inferred by us from the accumulated responses of the subjects. Our data generally confirmed the mentioned above models of direct current established in other studies, as held by the participants in the three groups (Table 1). The table shows, however, that in addition to the models previously reported, we identified two additional models, shown by our subjects: hybrid model-1 and hybrid model-2.

Group	Number	Unipolar	Hybrid 1	Clashing	Hybrid 2	Unidirectional	No
	of bulbs			currents			answer
Grade four	1	10	15	25	0	50	0
	2	0	0	17	0	60	23
Grade six	1	0	18	0	0	74	7
	2	0	0	5	2	89	4
Teachers	1	0	0	5	0	90	5
	2	0	0	0	0	100	0

 Table 1. Distribution of direct current models as held by the participants (%).

Hybrid model-1 (Fig. 5) presents a sort of intermediate model between the unipolar model and the more advanced models which include current through the entire circuit. Within this model pupils drew a closed circuit, but showed current flowing solely in one of the two wires



Figure 5. Hybrid model-1



Figure 6. Hybrid model-2

connecting the bulb with the battery. The circuit is mechanically closed, but not electrically closed. The current is apparently not conserved.

Hybrid model-2 (Fig 6) shown only by few pupils of sixth grade suggested a kind of a mixture between the clashing currents and unidirectional models. The current leaves the pole of the battery flows through most of the circuit whereas in a small part of

the circuit the current runs in the opposite direction.

In the teachers' group the variety of the current models was very small; almost all of them described the simple circuit within the unidirectional model while conserving the current.

The nature of the electrical current

Addressing electricity, the subjects showed a variety of images held. Pupils of the fourth grade regarded the electrical current as a continuous

flow of something, sometimes called electricity. Among the grade six participants only 18% regarded the current as comprised of particles. The particulate model of electricity was expressed by 70% of the teachers. The image of electricity held by all the teachers was dominated by the idea of current. Pupils provided several descriptions of electricity which included the ideas of electro-static as well as magneto-static nature, and the idea of a current (flow). We registered that the number of descriptive types of electricity decreased with the age of the participants.

The conservation of the current

The data show a clear positive dynamics regarding current conservation. The explanations provided by the fourth grade pupils showed that they do not conserve the current and regarded it as decreasing. 36% of the sixth grade pupils already conserve the electric current. Finally, almost all the teachers did conserve the electric current (80%).

Explanation of natural phenomena

When explaining natural phenomena and electrostatic demonstrations, the subjects showed a tendency to utilize a pattern of reasoning corresponding to a scheme of knowledge (e.g. Galili & Hazan 2000): the collision scheme. In different contexts this scheme manifested itself in several facets of knowledge corresponding to this scheme.

Discussion

The evolution of the models

Our study confirmed that children before instruction usually develop understanding of current within the unipolar model, considering it as plausible. The first change occurs when the necessity of closed circuit is realized. The evolution of pupils' **unipolar model** may include the hybrid stage when the current is shown only in one wire towards the bulb (this model was not previously reported). Seemingly this hybrid model precedes the development of clashing currents model.

Borges and Gilbert (1999) argued that accepting the electric current as a continuous flow and attributing the clashing currents nature to it in a circuit, delay further development of knowledge. This claim seems reasonable since the clashing current model shows rather high stability. We believe that several reasons can justify this model's stability.

The clashing currents model seemingly presents a manifestation of another highly inclusive scheme of knowledge. When the pupils explained the natural phenomena we asked them to address, their considerations often used the context of **collisions**, rubbing and at least touching between the bodies as reasons for things to occur. Thus thunder and lightning were attributed to collisions between clouds. This explanation was reported already by Piaget (1972). Bar (1989) found that rain was also attributed by children to the same cause: collision between clouds. In this investigation some participants said that clouds' collision created electricity causing thunder and lightning. Our participants stated that rubbing the comb caused it to attract the pieces of paper, and rubbing the clothes caused them to produce noise. The explanations pointed to colliding, rubbing, touching as building up electricity and responsible for the produced effects. From a rather young age children know that pushing against solid object causes pain, and colliding cars show damage and destruction. These experiences might affect the ideas that children produce facing questions regarding novel and puzzling situation. In this trend of thought, basing on our observations we ascribe stability to the **clashing currents model** among young pupils as being a facet of knowledge related to the more general scheme of collisions.

Moreover the clashing currents model offers a mechanical explanation, especially satisfying young children (Piaget 1972), for producing light in a bulb in electrical circuits containing a single bulb. Seemingly this also matches the well-known tendency in science itself through its long history (e.g. Descartes 1637/1965). Within this model of clashing currents children can provide correct predictions of whether the bulb gives light or not, although of wrong reasoning (Piaget 1972, Bar et al. 1994). This was also shown by Shepardson and Moje (1999) who reported that the most advanced of their students, who held the clashing currents model, did not progress beyond this model, but gave correct predictions regarding the light in the single bulb in the circuit.

To enhance the challenge to students' knowledge and to shaken the current model they hold, the pupils were faced with a circuit containing two bulbs. Following this step grade four pupils were more puzzled and, responded to this task by a relatively high percentage of those not answered (Table 1). However, the rate of the answers indicating the **unidirectional current model** increased, nonetheless not reaching the more advanced unidirectional model with conserved current. The latter did not appear; these pupils did not employ current conservation.

In grade six (age 11), following the two bulb circuit question, hybrid model 1 disappeared; a few showed hybrid model 2 with a fragment with a reversed current, and more pupils showed the unidirectional model (Table 1). All the teachers of elementary schools provided the unidirectional model and most of them conserved the current. All together, we observed that introduction of the two bulbs circuit has a generally effect in teaching direct current at both investigated ages of pupils, reducing unipolar and hybrid 1 models even in grade four.

Representation of the evolution of models as reflecting the development of understanding requires hybrid models, which may facilitate constructivist-based instruction. Each of the registered hybrid models combined features of less and more advanced models thus reflecting the dynamics of pupils' account for electrical circuit. The change of knowledge towards the more advanced model is seemingly more gradual than it was conceived before, passing through intermediate hybrids (Galili & Bar 1997).

Apparently, the problem of learning the current is to conceive it as a conserved quantity. We observed that the progress in this regard is parallel with imaging electricity as a particle flow. This means that one may suggest that encouraging the learners with regard to this image of electricity may improve their conserving the electrical current. The reason for that could be a better-visualized appeal of the material nature of current (Borges & Gilbert 1999).

Another general aspect of this study was observation of people's modes of reaction to the information or phenomena which conflict with their knowledge and views. Among the possible reactions were: keeping to the former views without hesitation, becoming confused and refraining from answer, developing their mental model, often hybrid constructs incorporating aspects of previous knowledge with the new ideas. All these reactions were recorded in our study as reflecting the evolution of models.

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Role play as a strategy to discuss spontaneous interpreting models of electric properties of matter: an informal education model

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Abstract

We investigated the ways that primary school pupils and middle school teenagers represent elementary electrical phenomenology using pictures and explanations, in the context of an analysis of the properties of materials. Simple situations were proposed, from which open discussions were developed.

The inquiry was articulated according to a path of increasing involvement of every pupil in representing each system under inspection, in an increasing role appropriation geared toward model construction. For this purpose role plays proved to be an important strategy in the context of electrical phenomena. The work method is set up as a model of informal activity and outcomes are proposed as data upon which one may build a strategy for the foundation of basic scientific education aiming at the construction of formal thinking in physics.

Introduction

Physics assigns a central role to the model as an interpretative instrument in the behaviour of systems (Hestenes, 1992; Grosslight et al., 1991). This makes it an essential tool in education (Hestenes, 1992; Snir, Smith & Raz, 2003; Gilbert & Boutler, 1998).

The interpretative role of scientific models requires a general vision that is often in conflict with the local/particular vision of the students, who as a result do not acquire these as interpretative instruments (Duit & Glynn, 1996; Gilbert & Boutler, 1998).

The idea of the discontinuity of matter and the idea of an explanatory model as a meta-concept in science for understanding the particulate model of matter are in particular difficult to internalise (Ben-Zvi, Eylon, & Silberstein, 1986; Novick & Nussbaum, 1978; Nussbaum, 1985; Wiser, 1994; Snir, Smith & Raz, 2003).

Connecting electrical and structural phenomena of matter is a possible way of responding to the varied, diffuse and persistent difficulties that students face in understanding microscopic interpretative models of electric phenomena overcoming the well known learning difficulties (Duit & von Rhöneck, 1998; Psillos, 1998).

We have thus built a sequence of stimuli for the exploration of interpretative models of some simple electrical phenomena as charging and discharging of simple objects by rubbing and touching.

The strategy for active involvement upon which cognitive laboratory activities of the type CLOE were based took the form of role play games.

The research questions we identified concerned:

- 1. spontaneity or the necessity of activating the process of building a model of non-macroscopic matter at a structural level;
- 2. types of explanation and sequences of reasoning subtended to spontaneous models of electrical phenomena in terms of processes of conduction rather than functioning models;
- 3. the characteristics of continuity/discontinuity, of causal or structural nature, local or global perspective, of spontaneous models.

Strategy and Method

The strategy of involvement and explication upon which cognitive laboratory activities of the CLOE (Cognitive Laboratories of Operative Exploration, Michelini, 2005) type were based was that of role play games¹⁴ (Blatner, 2002).

The CLOE laboratories are characterised by an activity carried out on a specific topic, following a semistructured interview protocol starting from the proposal of everyday life scenarios or the recalling of common situations; they provide researchers the indications concerning the students' conceptual paths and about the way in which they formalise knowledge (Michelini, 2005). In this specific investigation the

¹⁴ Of the three main types of role play games we have (Bonnet, 2000, Harwood, McKinster, Cruz, Gabel, 2002) we chose a type of game in which the participants take on the roles of characters and collaboratively create stories (Hall-Wallace, 2000, Richardson, 2000) to maintain the game dimension with its motivational value and to favour the personal involvement of the subject with the object of study.

preferred methodology was that of discussion in small groups supplemented by numerous graphicinterpretative activities and rogersian type interviews.

The strategy utilised was that of the inquiring method, whereby situations produced corresponding questions requiring description, interpretative role-playing games, the imagining of microscopic scenes and dramatising the experiences viewed; a moment of re-examining the experience concluded the activity.

The basic sequence (see Table 1) was proposed to primary school children (7-9 years), 43 pupils in 2 third grade classes and 50 pupils in 3 second grade classes, and to children of middle school (12-13 years), 36 pupils in 2 second year classes, all from East of Italy. Two second classes carried out activities for two hours, the remainder for one hour¹⁵. In the course of the activity the children compiled worksheets which for the older students required written replies and drawings while in the case of the younger children only drawings were required. In addition to these worksheets we also analysed the recordings of these sessions.

Situations	Activity type	Equipment	Activity description
1. Introduction	Cooperative	Pen or scissors and a piece of	Observation of a common object
	discussion	plexiglass	and a piece of plexiglass and
			informal investigation of their
			immediately accessible properties,
			recognising their different natures
2. Experience 1	Experimental	Pieces of paper on a table, a rod of	Observation of the action of the
_	_	plastic, two balls (one of aluminium,	"sticks" on the paper, before and
		the other of plastic kitchen film)	after having touched their edges,
		fixed on as many isolating supports	namely the balls, with the plastic
		made of everyday materials (the	rubbed on a synthetically covered
		"sticks").	seat
3. Recall	Cooperative		Identification and discussion of
	discussion		similar phenomena in daily life

Table 1: Description of the sequence

Data and Results

Middle school

The description of experience 1, where rod of plastic, charged balls and paper interact, highlighted the different natures of the children's ideas (see Table 2).

Categories of description	M class	T class	Children's replies
A. Attraction	12/19	1/17	the paper is attracted by the sticks
B. Attack	5/19	13/17	the paper attaches to the sticks
C: Connection between attraction and attack	1/19	1/17	the paper attaches to the sticks because it is attracted
D: Attraction equals effect	1/19	0/17	the paper attaches to the sticks or rather it is attracted to them
E: Connection between physical action and attack	0/19	2/17	that after having rubbed the stick on the seat and attaching transparent paper to the stick the pieces stuck to it

Table 2: Data about the description of experience 1

Already in the descriptive phase we distinguish two classes of responses: those that attribute a euristic subjectivity to the paper linked to pure phenomenological description, and those in which the action is attributed to an unspecified "being". This second group of students makes an interpretation when it is asked of them. Following the discussion about electrical phenomena (situation 3) only 4/19 pupils of the M class cite attraction as a characteristic common to all phenomena that have been classified as similar to those seen, and one cites magnetism.

When requested to explain what would have happened during the experience various interpretations emerge: the explanations (see Table 3) are of four types, always referring to an abstract "being":

A) model of energy

¹⁵ We report data from the activities about common experience 1, to compare all these different classes

- B) model of electric/magnetic particle matter
- C) model with opposing poles/charges
- D) model of force (magnetic)

Types of explanation	M class	T class	Children's replies
A: Model of energy	7/19	17/17 (heat form)	 -rubbing two objects together releases energy that provokes attraction with heat, by rubbing. Heat is transmitted
B: Model of electric/magnetic particle matter	4/19	0/17	when rubbed they lose cells and when put close together they attract and try to fill in the holes
C: Model with opposing poles/charges	2/19	0/17	that when you rub a thing hard it creates negative poles that attach to positive poles of something else
D: Model of force (magnetic)	4/19	0/17	rubbing two objects together creates a magnetic force

Table 3: Data about the explanation of experience 1

We must underline that the T class, where all students used the energy model, had studied thermal phenomena through the school curriculum, while the other had carried out an activity on magnetic phenomena the same morning. This data seems to indicate that in this phase, the children prefer their conceptual references over the models: there is a strong tendency to utilise reference models that are already present and we must make an effort to introduce new ones.

Drawings

Drawing 1

In the drawing of what happens in experience 1 we identify 3 categories:

- A) Exposition: references are made to necessary materials and there is no form of narration present, not even of the event itself;
- B) Narrative category: here we see the phases by which the phenomena has developed;
- C) Characterisation and explication only of situation result-product: they select a moment of the process, attract the paper, illustrate only this and at times make attributive comments. This strongly descriptive typology ignores all that leads up to the attracting phase of the paper.

In Table 4 we summarize the data and in fig. 1 we collect an example for each category.

	M class		T class	Total
	description	interpretation		
A. Exposition of materials used	3/19		1/17	4/36
B. Narrative category	5/19	3/19	6/17	14/36
C. Characterisation and explication only of situation result- product	5/19	1/19	10/17	16/36

Table 4: data about drawing 1 ("draw what happens in experience 1") in middle school classes

In type B, 11/36 pupils represented only the shapes, with some additions of words or picture elements that explained the actions; 3/19 pupils in the M class identified graphic elements of an interpretative nature quite clearly (fig.2). The drawing of figure 2 has an interpretative character with the attribution of roles to individual parts and a representation of the states of systems. This implies both the elements of causality and the correlation between actions and states, and the need to provide an interpretative model of the system.



Fig.1.Examples of classification of drawing 1: from top to bottom: typology A, B, C.

Fig. 2. Example of representation of the phenomenon with an interpretative character.



In category C we include a case in the M class, which interprets what happened without reference to the role of attraction, but to the preliminary action of rubbing on a t-shirt, focussing both upon the explicative principal occurring and upon its realisation (fig. 3).

Fig. 3. Interpretative representation isolated from the phenomenon of reference



Drawing 2:

In the drawing of the different objects (the rod of plastic, the aluminium and plastic film balls) before and during interaction (children were asked to imagine that they become so little as to enter inside the objects) we identify 3 main categories:

- A) sketch of the situation (fig. 4)
- B) state of the system before/after
- C) outside and inside observer¹⁶

In category B) different models are present:

- B1) the system as a whole changes its state (fig. 5)
- B2) elements that are components of the system change their state:
 - B2a) in structure, position... (fig. 6)
 - B2b) each element has an own state that changes (fig. 7).

In table 5 are summarized the data about drawing 2: only 2/36 pupils do not express a vision that differs from the concrete (1 fixes a macroscopic image, 1 does not draw). In some cases not only the material but also the surrounding space had a role, in a few cases this was the only aspect represented.

Table 5: data about drawing 2 (drawing of the different objects before and during interaction) in middle school classes

Categories of description	M class	T class	Total
A. Sketch of the situation	0/19	1/17	1/36
B1. Change of the state of the system as a whole	10/19	2/17	12/36
B2a. Change of structure, position of elements	2/19	11/17	13/36
B2b. Each element has an own state that changes	1/19	1/17	2/36
hybrid between B2a and B2b	2/19	1/17	3/36
C. outside and inside observer	1/19	0/17	1/36
not easily classifiable	2/19	1/17	3/36

Fig. 4: Drawing 2: example of type A: sketch of the situation



Fig. 5: drawing 2: examples of type B1: the system as a whole changes its state

¹⁶ Really describes somebody or oneself observing the system outside and inside



Fig. 6: drawing 2: examples of type B2a: elements that are components of the system change their state: in structure, position...



Fig. 7: drawing 2: example of type B2b: each element has an own state that changes



Primary school

Drawings

Drawing 1:

The drawing of what happened in experience 1 results in the second grade classes almost always as type C, but we find three drawings with graphic symbols (arrows) and several sentences ("the plastic film attaches more because it is smaller", for example) that seem to indicate a tendency towards interpretation.

In the third classes 27/43 drawings are type C; of the type B drawings, 11/22 have only two phases, with the illustration of the sticks before and after being charged, while 3/22 represent rubbing the piece of plastic in the previous phase (Table 6).

	Second grade classes	Third grade classes
A. Exposition of materials used	5/50	1/43
B. Narrative category	0/50	14/43
C. Characterisation and explication only of situation result-product	45/50	27/43

Table 6: data about drawing 1 ("draw what happens in experience 1") in primary school

Drawing 2:

In Table 7 we summarize the data regarding the drawing of the different objects before and during the interaction. In second grade classes we observe that in three cases of category A the drawing highlights a red zone on the materials, which corresponds to superficial areas where the plastic was rubbed. This representation acquires an even deeper meaning considering that with the recording of the activity it emerged that the stick attached to the paper because "it was red"; "because the loss of hair makes it…" "because it has those small things", or "… the plastic film is smooth, but the aluminium is rough and so it didn't really pick it up", or "the paper absorbed the electricity of this environment" and "because the electricity went there and picked up all the paper". The spontaneity is much more fertile at middle school rather than elementary school due to a limited capacity to explore and reflect rather than the types of models utilised.

Categories of description	Second grade classes	Third grade classes
A. Sketch of the situation	44/50	22/43
B1. Change of the state of the system as a whole	3/50	17/43
hybrid between B2a and B2b	0/50	2/43
B2a. Change of structure, position of elements	1/50	1/43

Table 7: data about drawing 2 (drawing of different objects before and during interaction) in primary school

From the analysis of the worksheets with pictures it results that almost all children of the second elementary class have a continuous vision of matter and do not see changes in objects before and after interaction. Considering the data of the third grade classes we note that around half of the pupils continue not to represent differences in the objects during interaction; the changes represented by the other half are in relation to external factors, not with the structure of the materials. In this way these typologies do not differ from the corresponding models of the middle school second grade.

Looking at the data from both primary and middle school pupils we observe that the description occurs in animistic (the paper attaches itself, the stick attaches to it) or causal (the stick produces an attraction/makes...) terms. The third case is the acquisition of a property by somebody. Thus there is a step

towards the reason why attraction occurs, though not an interpretation of how it happens. The explanations are evidently organised in terms of precise macroscopic or microscopic, or structural/organizational or quantum models (property of single elements of structure).

Conclusions

The representational potential of the children, combined with role play in the process that they are studying and interpreting, has a double value: to make them follow a reasoning in terms of models, to recognise and build them, and to build an interpretative foundation upon which to construct learning.

In relation to the research questions the results are:

1) a very fertile spontaneity exists even with regard to the disciplinary level of the production of models, and the activation of this production occurs with great ease and depth if we activate the cognitive instruments of personal involvement, in terms of games and utilising iconic representations for communication;

2) the types of representation emerge with clarity and coherence in terms of a disciplinary significance notwithstanding their ingenuous and elementary nature: the types of models that emerge are confirmed in the different phases, they overcome their local nature and assume a global character, and constitute the necessary basis for teachers to build an interpretation, which however is transmitted in selective and discontinuous terms;

3) concerning a continuity and discontinuity we substantially see two categories: that of total discontinuity, where there are particle elements or elements that are carriers of individual or collective properties, and then the category where rather than a continuity we see a system as being global: continuity is therefore absent.

The interpretation has three characteristics: a) "acquired properties": we must search for a property that is acquired by the system to behave differently from before; b) a modality to change behaviour; c) causality: a cause exists for the effects we have observed. Contrary to what happens in the major part of the children's spontaneous models as revealed by research, we find a surpassing of the local level with a vision often oriented both toward the global process and toward the global aspects of the system and its structure, and we feel that this is the result of having activated the modality of role play.

The role play game in the examination of electric properties, as in this case, was shown to be efficient in helping to reason in terms of models and in highlighting the possible models that may be the subject of discussion for teaching and thus to move toward a representation of the discipline.

The need for interpretative models confirms literature results, namely that there is a need to represent not only the states of a process but also the process itself, the need of state as something that is at a level superior to the representation of the process.

It is extraordinary that the models that emerge are the interpretative alternatives dominant in the field of physics: structural properties, properties of state, properties of organised systems, and this is a potential learning instrument that children possess, re-elaborate and share, rather than a series of hypotheses built outside of their learning process, that are communicated, described and transferred.

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Seeing a coin in the water from the air above - how it is and how it is explained in primary school textbooks

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Abstract

Discussion about light and the most common optics phenomena accompanied with some explanation starts in the science course at the upper primary school. It continues in the Physics course in high school, when deeper insight into the subject can be gained. When teaching refraction of light at the interface of two media, the teacher often illustrates the concept with some common examples from everyday life. A simple and very popular experiment that is frequently performed is with a coin, which is at first placed on the bottom of an empty glass. The observer looks at the glass bottom, but can not see the coin. Afterwards the glass is filled with water and an image of the coin appears in the field of vision.

We present a proper explanation of this and similar phenomena, which is not so trivial as it seems at the first sight, when one looks for it in science and physics textbooks. Some examples of inappropriate illustrations from textbooks are used to show that some of them suffer fundamental lack of understanding of how an image of an object is formed.

Introduction

A girl stands in a pool and her legs look short. Not just the observer's eyes, the lens of the camera get misled as well. A real image is formed on the camera's CCD, but the rays seem to come from some other point than they actually do. So, do we have a virtual image or virtual object where we see her legs?





How a virtual image is formed

Observer's eye catches rays from the point object (blue dot at depth -d under the water surface at z = 0 on Fig. 2) in a light cone at some angle β . To observer rays seem to emerge from somewhere else. Some not so trivial mathematics (Sears 1958, Bartlett et al. 1984, Nassar 1994, Johnson et al. 1995) is necessary to show there are actually two virtual images of the same point object. Both are short segments (the fact which is connected to the finite diameter of the pupil), perpendicular one to another and displaced from each other. Two partial virtual images are in Fig. 2 shown in red. The first partial image is at $z = z_1$ and is



apparent viewing angle is due to the refraction of light at the air – water boundary.

size of the virtual image of the fish that observer sees, depend on the position of the observer above the water level, as shown in Fig. 5. The air - water boundary is at z = 0. The fish is at depth z = -d. The observer is at height h above the water surface. The fish is represented by the blue line. Observers, who are at different positions above the water level, see the (astigmatic) virtual images of the fish at different places, in dependence of their positions, as shown in Fig. 5 (but only approximately, due to astigmatism). The shorter the



perpendicular to the plane yz and the second is placed on the z axis near z_2 . The complete virtual image is composed of two partial images and is astigmatic.

Position of the first partial virtual image (red dots) of the point object (blue dot) depends on the viewpoint of the observer, as shown in Fig. 3. The image is closer to the water surface and closer to the observer than the object. Two observers, who look at the same object which is under the water, do not see its image at the same place.

As a final result, an extended object in the water, like fish, seems larger and closer to the observer as it is, when the observer looks at it from the air. The main reason is increased viewing angle of the whole fish β_v for observing fish in the water from the air above, with respect to the viewing angle β_0 for observing the fish outside the water, see Fig. 4. Increase of the effection of light at the air – water boundary.





path of the light ray in the air, the more is the image of the fish deformed. Its nose and tail, seen under larger angles than the middle part of the body, seem larger and closer to the observer than the rest of the body.

Figures from textbooks for Science in the 7th grade in Slovene primary school

Due to recent changes in curriculum, the common light phenomena are now taught in the seventh grade of primary school which pupils of age 12 attend. Before that the light was discussed at Physics course at the end of the subsequent year with pupils one year older. The time meant to be spent on this subject was also contracted. Some unpleasant consequences unavoidably followed. Inadequate introduction of important conceptions is succeeded by superficiality in treating separate optical phenomena. Much of that can be found also in textbooks. In the following figures from primary school textbooks are presented and comments on them are given.



While we can accept the left part of the Fig. 7 if we assume it only shows that the fish is not where it is seen (but where?), the right part serves mostly to confuse. There are several superficialities – fish's nose is seen by the left eye and its tail by the right eye, some rays are doubled, one ray's extension ends somewhere and the other's doesn't. To see the whole fish it seems we



only need two rays – one from Fig. 5. Virtual images of the fish, observed from different viewpoints.



Ten and more years back there was only one available textbook on physics (Ferbar & Plevnik 1995) for primary schools in Slovenia. This illustration is taken from there. Except for the position of the virtual image, which is not entirely correct, this not so colorful drawing contains important attributes of the phenomenon appropriately. Not only one, but all the rays, emerging from the same point and finally reaching the eye contribute to a formation of the image of that point. These are the rays of the drawn light cone. This important concept of the light cone is missing from almost all subsequent textbooks.



the nose and the other from the tail. Fish indeed seems larger than actually is, but in reality it is also positioned elsewhere than drawn here.

Except for improving some technical parts of the figure, it remains almost the same except for some new defects that emerge

in subsequent edition of the textbook from the same publisher and authors (Fig. 8). In the upper part a virtual image of the fish appears, but it is in contradiction with the lower part of the figure – the fish and its image are of the same size in the upper part and of different size in the lower part. Image is displaced from the object in the upper part and on the same place as the fish in the

Fig. 9. Brancelj et al., 2003



lower part.

Back to the good old presentation: the fish was left out from the next edition (Fig. 9). Instead a pencil in a glass of water appears. A drawing is more appropriate as the previous ones; it is emphasized that more than just one ray must fall into the eye to form an image. Rather than formation of the image of the whole object it is shown, how an image of the point appears, with two rays emerging from the same point on the pencil. The position of the image is not drawn where it really is. Essentially the presentation is the same as presentation with a coin (Fig. 6). Figs. from 6 to 9 are from textbooks from the same publisher.



Legs in the water in Fig. 10 do indeed look shorter (closer to the water surface) when observed from the air above. But how can a 12 year old pupil understand how an image is formed from a drawing like that? One eye, one ray the image of a big toe can be anywhere on a dashed line. (For the whole image of the fish we just need two rays, one from the nose and the other from the tail, we have seen it before.) What is the clue which enables one to find the right position of the image?

Fig. 11 is from the same source as Fig. 10. Yes, when observing fishes in aquarium, one does not see them where

they are. There may be even more than just one image of the same fish visible at the same time, so it seems, there are two fishes. More suitable than drawing, would be a photograph of the situation in aquarium (see a photo in Fig. 12), maybe the same scene from two different viewpoints. Peculiar feature of this presentation are also the rays all entering the eye exactly in its center... And, apparently, for the whole image just two rays are needed, one from the nose and the other from the tail.

Fig. 12. How many fishes are in aquarium? This photo was taken from the corner, so the vertical line in the middle is the perpendicular edge of the container. There were two fishes, but we see their four virtual images.

The eye is looking a straw end (Fig. 13). How does a ray from the straw end travel through the water, glass and the air towards the eye? Drawing is bad, so one has to spend a little more time to notice the straw (upgrading it from the two rays entering the water and reflecting under strange angles as one at the glass bottom).



in a glass. When the glass is empty (except the coin) for the observer does not see

the coin, because it is hidden behind the glass wall. When the water is poured into the glass, the observer catches sight of the coin while changing neither his nor coin's position. This figure is appropriate. A minor remark would be only on the width of the light cone, bounded by the two rays: when compared to the size of the eye it is too large.

We prefer version from Fig. 6, showing a narrow light cone actually entering the eye.

While Fig. 14 from the textbook is acceptable, Fig. 15 from corresponding workbook suffers more imperfections. One ray from one point does not form an image of the point









alone, still less the image of the whole object. Moreover, the ray and its extension are drawn from points, which do not correspond to each other.

Fig. 16 is acceptable if it only shows how the light ray changes its direction at the water – air interface. But it can not be concluded how



and where a fisherman sees the fish from such a figure.

Conclusions

A general fault of illustrations from textbooks is mixing different levels of phenomenon when trying to explain its specific aspect. To illustrate the refraction of light on a different media boundary, just one ray need to be drawn. To illustrate a formation of a virtual image, the whole bunch of circumstances should be accounted for properly; otherwise the given "explanation" is merely a superficial quotation of the facts. Too often not much can be understood, although it is presented as an explanation. Frequently made superficialities found in textbooks are

- two rays which determine the viewing angle of the virtual image are often mistaken for rays which contribute to a formation of the virtual image;
- inference about the position of the virtual image of the point from tracking only one ray from that point;
- neglecting the important concept of the light cone containing the light rays emerging from the same point, which enters the eye and contribute to a formation of the image.

To our opinion, the old version of presentation of the phenomenon from Ferbar & Plevnik, 1995, resumed in Brancelj et al., 2003, and partially in Bajd et al., 2003, serves best to illustrate its origin on the level, accessible to pupils of age 12 and more. Understanding the formation of the virtual image which is a complex phenomenon itself should be a foundation for understanding higher level problems.

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Secondary School Physics

An Examination of Physics Subjects in the New National Curriculum for Science and Technology in Turkey

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Abstract

Currently there is an ongoing curriculum reform in Turkey starting from primary school curricula. This reform is now being extended to secondary education. The curricula for grades 1-8 are being implemented. In the second phase, middle school curricula are to be implemented by fall 2006. One of the aims of primary education is to prepare pupils for upper grades. From this perspective, the purpose of this examination is to check how the new primary school science and technology curriculum lays the foundation for high school physics education. The primary science and technology curriculum has many characteristics; it has seven learning areas with four strands supported by skills, understanding and attitudes; there is a spiral approach for each strand; mainly based on the constructivist approach; enriched with teaching activities and multiple assessment methods and techniques. The four strands are the following: physical processes, matter and change, living beings and life, and the earth and the universe. The physical processes strand includes three units which are force and motion, electricity in our lives, and light and sound. The concepts that are covered in each unit of the physical processes, and the earth and the universe strands have been examined according to grades and convenience for pupil levels. It is seen that there is a systematic structure embedded in the new curriculum. This structure guides the science teachers to enable them to address common student misconceptions in early years.

Introduction

The purpose of this article is to examine how the New Science and Technology Curriculum prepares pupils for upper grades. Specifically, the physical sciences subjects are inspected. One of the reasons for curriculum change and reform in Turkey is the need for a modern curriculum that reflects the current trends and approaches in science teaching and learning. Especially, in the past several decades the developing body of research has immensely showed that we need to change how we organize classroom learning environments and the way we teach. Also, extending learning experiences outside the classroom to provide significant positive life experiences for pupils has been shown that plays a vital role in meaningful learning. Therefore modern curricula have to take in to account students' past experiences as well as daily life experiences.

With the rise of Science-Technology-Society (STS) approach, related understandings, skills, and attitudes and values have all become an integral component of almost all science and technology curricula around the world. Hence, learning areas now include such components as well as the usual content areas. This is meant to enrich the student engagement in the core subjects.

The Structure of Turkish Education

Pre-school Education: Children who have not yet reached formal school age may attend preschool. Pre-school education is not compulsory. There are 550,000 pupils attending pre-school during 2005-2006 school year. The schooling rate (3-5 years old) is 20%.

Primary School: Children ranging in age from 6 to 14 are obliged to attend primary school. Primary school consists of eight years of schooling. There are 10,674,000 students attending primary school during 2005-2006 school year. The schooling rate is about 96%.

STRUCTURE O	STRUCTURE OF TURKISH EDUCATION SYSTEM				
U	niversities (Accept students in accordance with the result of the ÖSYS)				
Year 4, 21-22 years-old,	n				
Year 3, 20-21 years-old,					
Year 2, 19-20 years-old,	·				
Year 1, 18-19 years-old,					
The Student Selec	tion and Placement Examination(ÖSYS)				
-	Secondary School (Optional)				
Grade 12, 17-18 years-old,	Physics 12, Chemistry 12, Biology 12				
Grade 11, 16-17 years-old,	Physics 11, Chemistry 11, Biology 11				
Grade 10, 15-16 years-old,	Physics 10, Chemistry 10, Biology 10				
Grade 9, 14-15 years-old,	Physics 9, Chemistry 9, Biology 9 (Obliged)				
	Primary School (Compulsory)				
Grade 8, 13-14 years-old,	Science and Technology 8				
Grade 7, 12-13 years-old,	Science and Technology 7				
Grade 6, 11-12 years-old,	Science and Technology 6				
Grade 5, 10-11 years-old,	Science and Technology 5				
Grade 4, 9-10 years-old,	Science and Technology 4				
Grade 3, 8-9 years-old,					
Grade 2, 7-8 years-old,	5				
Grade 1, 6-7 years-old,	- <u> </u>				
	Pre-School (Optional)				
Kindergarten, 3-6 years-old,	n				
Day Nursery, 0-3 years-old,					

Fig. 1. The Structure of Turkish Education System

Secondary School: Secondary school consists of four school years and it is not compulsory. It covers general and vocational technical high schools (Technical Education schools for boys, Technical Education schools for girls, Religious education schools, and Commercial and Tourism Education schools). There are 3,258,300 students attending secondary high school during 2005-2006 school year. The total schooling rate is 85%.

Higher Education: Higher education mainly consists of four year schools. The number of universities reached more than 80 (includes private universities), and presently 2,074,000 students are enrolled in these universities. Today, higher education institutions in Turkey fall into three categories: universities, military and police colleges and academies, and vocational schools affiliated with ministries. The university is the principal higher education institution. It possesses academic autonomy and a public legal personality. It is responsible for carrying out high level educational activities, scientific research and publications. It is made up of faculties, graduate schools, schools of higher education, conservatories, two-year vocational training schools and centers for applied work and research. Nearly all institutions of higher education in Turkey have, each year since 1974, accepted students in accordance with the results of the ÖSYS examinations organized by The Student Selection and Placement Center (ÖSYM).

The Process of Curriculum Development

The Board of Education is the sole authority in Turkey for managing all processes for curriculum development. The board forms committees and makes appointments in order to achieve goals of the curriculum development in all subject areas. The recent curriculum change and reform efforts began in the summer of 2003 by soliciting and collecting opinions from different stakeholders including academicians, in-service teachers, teacher unions, etc. It also drew upon the accumulated data throughout the years from all around the country by researchers.

The Science and Technology curriculum development began in the summer of 2003 by a series of group meetings, and then a committee was formed by the Board of Education which included experienced teachers and academicians from different universities. The committee served for about two years and the new curriculum has been prepared. The authors of this article also served as committee members and intensely involved in curriculum development.

The Seven Learning Areas in the New Turkish Science and Technology Curriculum

In Turkey, Science and Technology is included as a compulsory course from grade four (ages 9-10) to eight (ages 13-14).

The new Turkish Science and Technology has seven learning areas. These are the following:

- Physical Processes
- Life and Living Beings
- Matter and Change
- The Earth and the Universe
- Science Process Skills (SPS)
- Science-Technology-Society-Environment (STSE)
- Attitudes and Values (AV)

While the first four of these represent the content areas, the remaining three are interwoven into them throughout the grades. Although, they are not included as separate units they are visible in all content area units. This approach clearly indicates the intent of having pupils engaged in student-centered activities while learning the content. Learning by doing is seen to be a central pillar of the new curriculum.

The Three Interwoven Learning Areas in the Curriculum

One of the features of the new curriculum is that the SPS, STSE and AV outcomes are identified and defined in the curriculum for the first time appropriate for level and grade. With the new curriculum materials and the textbooks floating around the related outcomes have been increasingly visible in school science contexts. It is also our experience that in the science education departments at the universities and conferences these notions are becoming more and more popular among the academicians and researchers. It is also deemed that future science education research will also benefit from the new curriculum



Fig. 2. The Structure of The New Turkish Science and Technology Curriculum

The New Turkish Science and Technology Curriulum-2005

Technology Dimension of the Curriculum

For the first time in Turkish primary education a technology component is being integrated into science education. It is deemed necessary and inevitable to understand both the nature of science and technology during compulsory formal education. The structure of the curriculum is founded so that students may bring their daily life experiences to classroom and, conversely, can take out their school experiences outside the school borders. In order to realize this precept several activities have been proposed that can incorporate many related curricular outcomes to technology understandings. Traditionally the science courses in primary education had been called literally "science knowledge." Whereas the committee thought that this leads students and people to think that science is only made up of some certain knowledge. In order to make the curriculum reform more meaningful, a name change was considered and to reflect the technology incorporation it is now being named "science and technology." Here we need to emphasize that the term "knowledge" has been intentionally removed from the name of the course. Another big improvement was made in the weekly course hours. It has always been the case that science courses in grades 4-8 were given a 3 hour period per week. With the current reform efforts the weekly hours are increased to 4 hours per week. Here we should also mention that there is a separate course entitled "design and technology" that allies with science and technology. With a new curriculum that two hours per week course also will help science and technology teaching and learning by bringing technology to the center and giving students more opportunities for activities and applications.

Approaching Student Misconceptions in the New Curriculum

The greatest triumph of the science education research in the last several decades has been to uncover and put light on to student misconceptions and related learning difficulties. The new curriculum, where appropriate, prompts teachers to such important student misconceptions identified in the literature. Another purpose is to alert also the teachers to those wide spread misconceptions since often times the teachers themselves, as seen many times, may have such long time held persistent misconceptions themselves as well. Therefore the new science and technology curriculum has a second mission: to educate the educators and the public! The authors have seen the benefit of this approach during the several in-service teacher development seminars prepared and delivered in conjunction with the current reform efforts.

The Approach to Student Assessment and Measurement of Learning in Science

The new curriculum adopts a multi level and multi faceted measurement and assessment approach to student learning. Again the research literature has shown that evaluating the process and integrating measurement and assessment into teaching and learning has more potential to bringing light onto what students actually learn. Therefore the new curriculum urges teachers and educators to use, where appropriate, more of such formative learning assessment and measurement techniques rather than usual paper and pencil tests. Among them many alternative measurement methods and techniques can be listed ranging from developing a student portfolio to group activities, and to peer evaluation. The big idea is that students can learn more meaningfully when they are motivated and engaged in their own learning. Thus the overall teaching strategy must take advantage of all methods and techniques during all stages of teaching and learning.

The role and importance of developing and using models and modeling in science is also emphasized in the new curriculum. A special emphasis was given to developing understandings that models have shared and unshared attributes with the target and that scientists always use develop and use models in order to visualize their thinking and testing theories.

Grade	Units
4	Force and Motion Light and Sound
	Electricity in Our Life Our Planet Earth
5	Force and Motion The Earth, Sun and Moon Light and Sound Electricity in Our Life
6	Force and Motion Electricity in Our Life Matter and Heat Light and Sound What the Crust of the Earth is Made up of?
7	Force and Motion Electricity in Our Life Light The Solar System and Beyond: The Puzzle of Outer Space
8	Force and Motion Sound Phases of Matter and Heat Electricity in Our Life The Natural Processes

Table 1. The units of the physical processes learning area in each grade

The Units in the Physical Processes Learning Area

The physical processes learning area consists of several units that may change according to grades (see Table 1)

The Spiral Structure of the Science and Technology Curriculum

The New Science and Technology curriculum has a spiral structure for each unit, for instance Force and Motion unit is taught at all grades from 4 to 8. It is also applicable for the other units. To show spiral structure of the new curriculum, the concepts of Force and motion units for each grade are given below as concept map.

Fig. 3. The concept map of force and motion unit in science and technology 4 curriculum





Fig. 4. The concept map of force and motion unit in science and technology 5 curriculum



Fig. 5. The concept map of force and motion unit in science and technology 6 curriculum



Fig. 6. The concept map of force and motion unit in science and technology 7 curriculum



Fig. 7. The concept map of force and motion unit in science and technology 8 curriculum

The Effectiveness of the New Science and Technology Curriculum

The new science and technology curriculum for grades 4-8 is currently being implemented in a step by step way. Grades 4 and 5 began using the new curriculum first; and then in the middle grades starting from 2005-2006 a pilot implementation is done first for grade 6 to be followed by whole country implementation in 2006-2007 school year. Every consecutive year a new grade will first pilot the curriculum and then begin using it. Hence by 2008-2009 all grades in primary education will be using the new curriculum.

While on one hand the implementation is carried, on the other hand new studies concerned with the effectiveness of the new curriculum are being conducted. Although they are just a few at the time, it is worth mentioning about the findings here. One of such studies was concerned with the effectiveness of the new curriculum on developing students' science process skills (SPS) (Basdag, 2006). A total of 457 students (227 students who followed the 2000 science curriculum (control group-CG) and 230 who followed the 2005 science and technology curriculum (treatment group-TG) participated in the study. The science process assessment for elementary students (Smith, 2003) was used in order to measure the students' SPS. This paper and pencil test takes about 40-50 minutes and includes 40 items on 13 different SPS: observing, classifying, inferring, predicting, measuring, communicating, using space/time relations, defining operationally, formulating hypotheses, experimenting, recognizing variables, interpreting data, and formulating models. On 12 of 13 SPS students in the TG received higher averages than those in the CG and on 8 of these SPS the difference between the averages are statistically significant. On only one of the SPS (namely, recognizing variables) students in the CG received a higher average but the difference is not statistically significant. It is also noteworthy that students in each group received lowest averages on "formulating models", while they received highest averages on "measuring". When results were analyzed according to students' gender and socioeconomic status it is seen that while students in each group showed no difference according to gender a statistically significant difference was found among the CG favoring the high socio-economic status whereas there is no difference in the TG.

Another study was conducted to measure teachers' views about the new science and technology curriculum (Sahin, 2006). 56 teachers from 39 different schools and 6 different provinces piloting the curriculum participated in this study. It is seen that practicing teachers are highly favoring the new one as compared the previous one. In still another study students attitude toward science courses were measured (Dalkiran, 2006). It was found that the 6th grade students' who were enrolled in the schools piloting the new curriculum showed more favorable overall attitudes to a 28-item scale.

Secondary School Physics Curriculum

Starting from 2005-2006 school year secondary education has become a four year study (previously it was three years.) The curriculum reform is now being extended to secondary education. Inevitably, high school physics and other science subjects will have to follow the new science and technology curriculum and build on top of where students were left at grade eight. The physics curriculum development effort has begun in January 2006. Although the process is now in early stage it is determined that physics will be taught in all four years (only the 9th grade course being compulsory) as two hours per week in grades 9 and 10; and 3 hours per week in grades 11 and 12. The elective physics course will be taken by upper graders if they choose science as their major study area. It is nearly decided by the committee that the physics subjects will be included in a spiral way through the years, there are six learning areas (Force and Motion, Waves and Optics, Matter and Energy, Modern Physics and The Earth and Beyond), and a context based approach to be adopted. The Physics curriculum development process is ongoing process, and will be completed at the end of 2007.

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The role and place of energy in the physics curriculum

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Abstract

Traditionally, energy is one of the last concepts introduced in the classical mechanics curriculum. It follows after the concepts of force and work. Energy is generally considered to be an abstract concept and difficult to define. Nevertheless, energy is central to all of science and, together with matter it makes up the universe (Hewitt, 2002). In this paper we reason that energy is a basic concept that should introduce the study of physics, because learners' intuitive ideas about this concept do not differ as much from the scientific as is the case for the force concept. Furthermore, energy is a unifying concept in physics and the conservation of energy a unifying principle that is encountered throughout the physics curriculum. The energy concept does not undergo essential changes from classical to modern physics like the force concept, although its meaning is broadened. The role and place of energy in the physics curriculum is considered from didactical, linguistic, philosophical and epistemological perspectives.

Introduction

Augustine said about the concept of time: "What then is time? If one asks me, I know. If I wish to explain it to one that asketh, I know not ..." (Barnett, 1998). The same is true for the concept of energy. Like time, energy is an abstract concept, but also something experienced by everybody. It is undefinable, but characterizable. It is impossible to describe, but easy to understand. Energy is what make things happen, the prime cause (in the physical, not theological sense). Nothing happens without energy, and everything happens as result of it.

Historically the concept of energy was formally brought into physics more than 150 years after Newton's work (Gribbin, 2002). Following the historical sequence most introductory physics textbooks introduce the concept of energy after the concept of work which follows force and Newton's laws. This order makes sense in a formal approach to physics teaching where the unit of force (newton) is built up from the basic units of kilogram, meter and second. The unit of work and energy, namely the joule, is then derived from the newton. However the formal approach and order has unfortunately caused learners to perceive classical mechanics as a "disconnected jumble of many special purpose formulas" (Chabay & Sherwood, 2004:439) and causes serious misconceptions, especially about the concept of force. Although a large variety of conceptual, inquiry and other constructivist teaching-learning approaches led to an improved understanding of the concepts of classical mechanics, physics remains foreign to learners.

The question asked is whether the historical order should be maintained in a contemporary approach to physics teaching. Didactical, linguistic, philosophical and epistemological reasons are given to support the assertion that the energy concept should introduce the physics curriculum.

Constructivist didactical approach

Children interact from a very early stage with their surroundings to become practically acquainted with it. They observe and explain physical phenomena. Common features (such as egocentrism and context-specific descriptions using qualitative, comparative terminology) in learners' alternative frameworks, together with the consistency found in their alternative views of physical concepts, indicate the usage of an alternative paradigm to explain the physical world (Driver & Easley, 1978; Lemmer *et al.*, 2003; Lemmer *et al.*, 2005).

According to the constructivist teaching-learning theory learners' experiences and preknowledge should be the starting point of teaching. Although this idea is implemented in most contemporary approaches to physics, the subject is still not introduced within a paradigm and perceived coherently (Lemmer & Lemmer, 2005). Concepts are treated individually in order to accomplish conceptual change. The force concept is central in the traditional physics curriculum. However, this concept has been found to be counter-intuitive and consequently causes alternative conceptions that are strongly held and difficult to remedy (Watts, 1983; Thijs & Van den Berg, 1995, Planinic *et al.*, 2006). A learner's intuitive schema of force and motion has to undergo a massive transformation in order to adapt to the scientific concept of force (Rowlands *et al.*, 1999).

Although the concept of energy also yield conceptual difficulties and alternative conceptions, these can be dealt with more easily than those associated with force. Trumper (1990) identified three pervasive alternative frameworks, namely the anthropocentric framework (energy is associated mainly with human beings), the 'active' deposit framework (energy as causing things to happen) and the 'product framework (energy as a product of some processes). Trumper (1990 and 1991) presented instructional strategies to deal with these three alternative frameworks. The first framework can be rectified by means of examples of human and machine performing the same task in the same way. The second and third frameworks are not scientifically unacceptable, and can be generalized to establish the complete scientific framework. In these studies learners were guided to create a new scientifically correct schema that was based on their own preconceptions. Duit (1981) proposed the use of semantic anchors to improve understanding of energy conservation. An example of such a semantic anchor is to link energy to learners' everyday experience of fuels, namely that energy is necessary when something is to be set in motion, quickened, lifted, illuminated, heated, etc. Energy conservation is then approached in a step-bystep manner by means of examples and experiments. Introduction of the concept of energy degradation, was found successful in learners' understanding of energy transformations and conservation (Pinto et al., 2004). From these literature studies it follows that the concept of energy appeals far more to learners' experience than the concept of force. It leads to fewer alternative conceptions that are less resistant to change.

For the concept of energy, an evolutionary rather than revolutionary conceptual change process can be followed to enable learners to build the appropriate scientific concept (Trumper, 1990). The scientific concept of energy is assimilated rather than accommodated. For the force concept a revolutionary conceptual change (through cognitive conflict) is needed and a major accommodation is necessary. It can be deduced that physics could be learned more effectively if different manifestations of energy and transformations between them are introduced first. After the energy concept has been established it can then be the anchoring concept for understanding the more difficult concepts of force and work in mechanics. The concept of work follows from the existential definition as the change in energy. A force (external agent) can do this work. The change in kinetic energy (and thus velocity) can conceptually be connected with the concept of acceleration. For conceptual understanding a change in the order of introduction of the concepts from that of standard introductory physics curriculum is therefore proposed. Thereafter the concepts can be treated formally while constantly referring to the conceptual meanings.

Throughout physics teaching, it should be emphasized that the paradigm of physics differs from that of everyday life, and special (formal) meanings are attached to concepts such as force and work (Osborne *et al.*, 1983). It is didactically accountable to proceed from everyday situations to idealized situations and then to formalization (generalization). A contextual approach starts from learners' primordial paradigm, proceeds towards conceptualization and then to formalism. This approach differs from the conventional didactical approach in physics which moves from the idealized situation (e.g. frictionless surfaces) to generalized (e.g. Newton's laws) to real situations (e.g. including friction) (Lemmer *et al.*, 2005).

Linguistic reasons

Wilardjo (1990) discusses numerous examples of problems with terminology in Indonesia and Malaysia. This is common in languages in the developing world where appropriate terminology has to be developed. Although the usage and formal meanings of scientific terms such as force, energy and power have become well established in the technologized european languages, ambiguity still leads to misconceptions. An example is that electrical *energy* producers are called *power* stations in English and *force* stations in German, Dutch and Afrikaans. Words with such diverse and confused meanings in everyday language are difficult to formalize in science.

Learners, however, intuitively grasp that "energy is what makes things happen". This view is embedded in everyday language. The everyday meaning can be expanded to the scientific meaning, as demonstrated by Trumper (1991).

Philosophical questions

A primary goal of physics is to know and understand the world by studying its basic phenomena. In mechanics the phenomena of motion is studied. In order to understand motion, the following series of questions should be considered (Lemmer & Lemmer, 2005):

- 1. Why do objects move at all?
- 2. Why do objects move fast or slow?
- 3. Why do objects keep on moving after being kicked, thrown, released, etc.?
- 4. Why do objects move faster or slower?

This series of questions forms a cognitive and logical hierarchy, i.e. the questions are in order from most basic to advanced. The first two questions deal with energy; and the third with momentum. The fourth question, which is the most complex, relates to forces. This question can only be addressed effectively after the answers to the first three are understood. The traditional teaching order starts with question 4, purely because of history.

The series of questions given above is not only didactically and cognitively logical, but can also contribute to the prevention or elimination of alternative conceptions regarding force. Two persistent miscomprehensions are that forces cause motion and forces sustain motion. Halloun and Hestenes (1985) connected these ideas with the pre-Galilean notion of impetus. The impetus concept is a historical precursor of the concepts of kinetic energy and momentum. By introducing energy first, learners' alternative conceptions of force can be remedied or even prevented. Instead of perceiving force to be the *causa motio* and the sustainer of motion, the learners are given other options that connect with their primordial ideas, namely that energy is the *causa motio*, and momentum sustains motion and always acts in the direction of motion. Force can then be introduced as the *external* agent that *changes* motion (i.e. causes acceleration). From personal experience, learners readily accept and apply this.

Epistemological aspects

The preceding analysis and argument focus on mechanics, because alternative conceptions of the force concept initiated our work. Having once arrived at the point of view that mechanics should be taught with the energy concept as cornerstone, good reasons were found to make it the cornerstone, in fact the effective paradigm, for all of physics education.

Traditionally, Physics is taught as a collection of separate fields, each departing from a different concept, e.g. mechanics starts with the force concept, electricity with electric current and thermodynamics with temperature. From the energy perspective, different fields of physics can be presented in a consistent, logical way. Several physics education researchers developed a new order of presentation of different fields of physics, each starting from the energy concept. Examples are: Wesi (1998) evaluated the introduction of electricity from an energy perspective. Forms of energy can be used as a starting point for teaching thermodynamics when certain terms are reformulated (Kaper & Goedhart, 2002). Starting from energy, Neuenschwander *et al.* (2006) derived a quantity called action that can be used to predict motion in the newtonian world, the quantum world as well as in the curved spacetime of general relativity. Furthermore, conservation laws and symmetries enable students to predict whether a given elementary particle reaction is possible and then derive other possible reactions (Van den Berg & Hoekzema, 2006). A teaching method that focuses on the general principles has been successfully implemented. The results of these research studies show that physics can be presented effectively departing from the concept of energy and the principle of conservation of energy. The energy concept is thus a basic and unifying concept.

Conclusions

Outcomes of a curriculum has to be seen as a process in which learners are actively involved in constructing a view of the world closer to the scientific view (Trumper, 1991). The egocentric and context-specific primordial paradigm used by learners should be changed into the formal, non-personal and generalized paradigm of physics (Lemmer *et al.*, 2005). A paradigm change can only be accomplished by teaching physics from a perspective that takes into account learners' experience of reality, the nature and structure of physics and philosophical questions.

Teaching physics from the perspective of the concept of force leads to a deviation of learners' experience of reality, while starting from energy gives rise to a convergence between theory and experienced reality (primordial paradigm) in learning. The divergence caused by the force concept lies in the need to idealize unrealistically and in explanations that are contrary to experience, for example that an object moves with constant velocity because no net force acts on it. This notion is complicated by explaining that any number of forces acting on the object are precisely balanced. This scientific view requires the insight of a Newton from each and every student. If we depart from the concept of energy, we depart from reality instead, rather than idealization. Using the energy paradigm means that the educator can commence with actual experience and observed reality in all its complexity and formalize it through simplification (e.g. ignoring friction) instead of idealization (e.g. a frictionless world). Alternative conceptions of concepts such as force can be remedied, or even circumvented. Giving the energy concept a central role in the physics curriculum can consequently improve learners' understanding of physics.

What is required is a new structure for learning, teaching and understanding physics; one that has a constant and consistent foundation (unifying concept), which provides a new paradigm on which to (re)construct a new formal structure of models, theories and laws. Such a concept exists; it has just not been used as such. The underlying unifying concept of physics is energy. Indeed, physics can be characterized as the study of the manifestations and transformations of energy.

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Stick-Slip Dynamics: Oscillations with Friction. For Undergraduates

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Abstract

Stick-Slip motion is the basis for the description of a great variety of phenomena characterized by the presence of sliding friction between bodies with elastic features. In this article we describe a simple experimental equipment for the analysis of this kind of dynamics. A wide set of possible experimental observations and measures is presented. We tested this equipment at the university of Naples "Federico II" in courses for undergraduate students and in the teacher training school for secondary education. We are now performing an analysis of the educational impact.

Introduction

A large number of natural phenomena characterized by very distinct aspects, both qualitatively and quantitatively, share common alternating dynamics in specific circumstances. These dynamics are characterized by alternating phases: *static* phases where the system accumulates potential energy and *dynamic* phases where this energy is transformed in kinetic energy. These phenomena are similar, in a more or less abstract way, to the problem of the sliding motion with friction of a body with elastic properties and are usually referred to as stick-slip processes [1-5].

Figure 1 – Examples of stick-slip motion. a) Frame extracted from an animation showing the motion of grains of sand in a rotating cylinder: grain speed increases from blue to red. b) Violin string and bow



Many other processes with two intermittent phases can be traced back to stick-slip processes. Landslide motions (Figure 1a), the creaking of a door slowly opened, the motion of a windscreen wiper on a dry glass, the sound generated when a fingertip moves along the edge of a glass, the squealing of a chalk on a blackboard, the sound emission mechanism of a violin (Figure 1b), are common examples of stick-slip processes. Many other examples may be found in a variety of mechanic processes, both artificial (braking of cars and trains) and natural (earthquake generation [10] and avalanche dynamics [9]). The most simple physical system that exhibits a stick-slip dynamics consists of a body having mass M, that slides on a plain surface with friction. The body is pulled by a spring with elastic constant k, in such a way that the free end of the spring moves with a velocity v (Figure 2). For the sake of simplicity, we can consider a physical system equivalent to the former, where the body is connected to a wall by means of a spring, while a rough plain slides at constant speed under the body. We will use the acronym SS to denote this Strained Spring system, and the acronym FS (Free Spring) to denote the previously mentioned system (Figure 3). The two system are related to each other by means of a simple coordinate change.

Figure 2 – Free Spring system(FS)



Figure 3 – Strained Spring system (SS)



You can get an idea of the intermittent nature of the SS system dynamics, with alternating stick and slip phases, by means of an animation frame created with Interactive Physics (Figure 4).

Figure 4 – Animation created with Interactive Physics, that shows the dynamic of the body in the SS configuration of Figure 3. The plain moves with speed *v* and the vector FF represents the friction force. The two graphs show the position of the body and the friction force acting on it as functions of time



Equation of Motion

Let x=x(t) be the position of the body in the SS system. Assume that the origin of the reference frame is located in the position occupied by the body at the time t=0, and that in such an instant the spring is released. At t=0 the plain starts to move with speed *v* under the body. The equation of motion is given by

$$M\ddot{x} = F_s - F_{el}$$

where F_s is the static friction and F_{el} is the elastic force generated by the spring. In each instant following t=0, the static friction equals the elastic force and the body remains united with the plain (stick phase). Therefore its motion is described by the equation

At a specific time t_l , the elastic force of the spring

$$F_{el} = kx(t) = kvt$$

equals the critical value of the static friction force

$$F_{\rm max} = \mu_s N = \mu_s M g$$

where N=Mg is the strain reaction and μ_s is the static friction coefficient, which is assumed to be independent of the contact surface [6]-[7]. Starting from t_1 , the body slides back along the plain (slip phase), subject to the elastic force and dynamic friction force:

$$F_d = \mu_d N = \mu_d M g$$

where μ_d is the dynamic friction coefficient.

We assume that the dynamic friction coefficient does not depend on the speed v, the mass M, and the contact surface [6,7]. Thus, the equation of motion for the slip phase is given by

$$M\ddot{x} = F_d - kx(t) \tag{1a}$$

with initial conditions

$$\begin{cases} x(t_1) = \frac{\mu_s N}{k} \\ \dot{x}(t_1) = v \end{cases}$$
(1b)

If we define a new coordinate y=y(t) for the position of the body

$$y(t) = x(t) - \frac{F_d}{k}$$

the equation of motion becomes

$$M\ddot{y} = -ky(t) \tag{2a}$$

with initial conditions

$$\begin{cases} y(t_1) = \frac{(\mu_s - \mu_d)N}{k} \\ \dot{y}(t_1) = v \end{cases}$$
(2b)

This equation admits a solution of the type

$$y(t) = A \cos (\omega t + \varphi) = A \cos \omega t \cos \varphi - A \sin \omega t \sin \varphi$$
,

where *A* and φ depend on the initial conditions, and $\omega^2 = k/M$. If we choose $t_1 = 0$ as initial time, with the initial conditions (2b), we get

$$y(t) = \frac{(\mu_s - \mu_d)N}{k} \cos \omega t + \frac{v}{\omega} \sin \omega t$$
(3a)

from which x=x(t) in the slip phase is given by

$$x(t) = -\frac{\mu_d N}{k} + \frac{(\mu_s - \mu_d)N}{k} \cos \omega t + \frac{v}{\omega} \sin \omega t$$
(3b)

First, let us limit ourselves to the low speed range, when the following inequality holds

$$\frac{v}{\omega} = v \sqrt{\frac{M}{k}} << \frac{(\mu_s - \mu_d)N}{k} \tag{4}$$

In such a case the term containing *sinwt* in equation (3b) can be neglected and the motion of the block in the slip phase is an harmonic oscillation whose amplitude $(\mu_{s}, \mu_{d})N/k$, for fixed values of M and k, is completely defined by the difference between static and dynamic friction coefficients (to get an idea of the orders of magnitude such that this occurs, observe that for M=IKg, k=IN/m, and $(\mu_{s}, \mu_{d})N=IN$, we get v <<Im/s). The slip phase actually ends after half an oscillation, when the body acquires again the speed v, i.e. when it is again united with the plain. Subsequently, stick and slip phases alternate periodically. A combination of the time law for the stick phase, x(t)=vt, and the time law for the slip phase,

$$x(t) = \frac{\mu_d N}{k} + \frac{(\mu_s - \mu_d)N}{k} \cos \omega t , \qquad (5)$$

gives us the motion of the block plotted in Figure 5.

Figure 5 - SS – Graph of x(t). Red lines represent stick phases, blue lines represent slip phases. This color code is used in all the following figures



When the speed is not too low, and more generally when

$$\frac{v}{\omega} = v \sqrt{\frac{M}{k}} \ge \frac{(\mu_s - \mu_d)N}{k} \tag{6}$$

the previous approximation is not acceptable, and relation (3b), which describes the slip phase, must take into account the non-negligible contribution of the last term. In such a case, the overall motion of the body is represented by the graph shown in Figure 6.

Figure 6 - SS - Graph of
$$x(t)$$
 for the exact solution (3b)



Dependence of the motion on the speed of the sliding plain

Let us try to find the characteristic features of the motion when the speed of the sliding plain changes, forcing all the other parameters to stay constant. What happens is that, when v increases, the stick phase becomes shorter and shorter, until it disappears in the infinite speed limit. Let T_{stick} be the duration of the stick phase. We get

$$T_{stick} = \frac{2(\mu_s - \mu_d)N}{kv} \approx \frac{const.}{v} \,. \tag{7}$$

The duration of the slip phases can be obtained differentiating relation (3b) and requiring that

$$\dot{x}(t) = v, \qquad (8)$$

since the slip phase ends when the motion of the block is again the same as the underlying plain that moves with speed v. Let T_{slip} denote the duration of the slip phase. It is easy to see that one possible value is

$$T_{slip} = 2\pi / \omega = T$$

This solution clearly represents the limit condition where no stick phase occur. The other solutions of equation (8) are shown in Figure 7 together with the values of T_{stick} . For small speeds, the stick time diverges while the slip time tends to T/2, i.e. just the value we used in the low speed approximation. When the speed increases, T_{stick} exhibits a fast decrease and asymptotically tends to zero, while T_{slip} tends to its asymptotic value T. In the neighborhood of a certain critical value v_{crit} of the sliding speed (in the case shown in Figure 7, $v_{crit} = 0.42$ m/s) there is a cross-over phenomenon that quickly brings the system from configurations where $T_{stick} >> T_{slip}$ to configurations where $T_{stick} << T_{slip}$. For speeds much greater than this critical speed, the stick phase is practically non-existent and the motion can be approximated as a simple harmonic oscillation.

Figure 7 – Graphs of T_{stick} (red) and T_{slip} (blue) for the following values of the parameters: M=1 Kg, k=25 N/m, $\mu_s=1$, $\mu_d=0.5$. The period T of the harmonic oscillations is about 1.3 s



Phase space

Now we want to analyze the characteristic trajectories of the stick-slip dynamics in the phase space. For the sake of simplicity, we limit ourselves to the case when the slip phase is described by equation (5):

$$x(t) = \frac{\mu_d N}{k} + \frac{(\mu_s - \mu_d)N}{k} \cos \omega t$$

In such a case (see Figure 8), stick phases will be represented by a segment parallel to the position axis and lying on the straight line $\dot{x}(t) = v$ (the length of the segment concerning the first stick phase is different because $x(t_0)$ changes (see equation (7)), while slip phases will be represented by half-circumferences (harmonic half-oscillations) whose center is in the point having coordinates

$$x = \frac{F_d}{k} = \frac{\mu_d N}{k}, \qquad \dot{x} = v,$$

and with radius equal to

$$\frac{F_{\max} - F_d}{k} \equiv \frac{(\mu_s - \mu_d)N}{k}$$

Figure 8 – Phase space trajectory of the stick-slip dynamics described by equation (5).



The experiment

Now let us describe the experimental device we used. The block is a wooden parallelepiped whose weight is approximately 650 g (inclusive of the weight of the position sensor mounted above it) with a side covered by a rubber layer. This side of the block is put above a strip of cloth whose sliding motion can be driven by means of a handle connected to a cylinder. It is not difficult to move the handle of the cylinder in such a way that the cloth slides on the workbench at an approximately constant speed. The block is connected by means

of a spring to a force sensor that measures the tension of the spring. The force sensor is inserted in a flat screen, which is orthogonally locked to the wooden table around which the strip slides. On top of the block there is a position sensor (sonar) that measures the position of the block relative to the flat screen. Both the sensors are interfaced with a PC (by means of the LabPro software package). The software generates and displays directly the graphs of the observables (spring tension, position, speed, and acceleration of the block, and all the physical functions that can be evaluated from them) as functions of time. In Figure 10 we show a picture of the experimental device. In Figures 11-14 we show the graphs of some of the measured quantities (For M = 0.650 Kg, k = 22 N/M, and v = 0.06 m/s)



Figure 10 – The experimental device

Figure 11 – Graph of the measured block position



Figure 12 - Graph of the measured block speed



Figure 13 – Graph of the measured block acceleration



Figure 14 – Graph of the measured spring tension



From the previous graphs we found

Table 1 – Experimental results

$$v = 0.058 \pm 0.002$$
 m/s
 $k = 21.6 \pm 0.9$ N/m

$$F_{\text{max}} = 6.9 \pm 0.1 \text{ N}$$
 $\mu_s = 1.08 \pm 0.02$
 $F_d = 4.1 \pm 0.1 \text{ N}$ $\mu_d = 0.65 \pm 0.02$

In Figures 15 and 16 we show the graphs of some "calculated" quantities

Figure 15 – In this graph we show the energy as a function of the time (same data as in Figures 14 and 15)



Figure 16 – Phase space trajectory (same data as in Figures 14 and 15)



Conclusions

We presented a wide variety of didactic opportunities given by the simple stick-slip device we designed and implemented. What in our view seems to be very useful is that one has, on the one hand, the opportunity to perform very simple observations related to the dynamics of the block (time law, elastic force, friction) and to measure all the physical quantities related to it and the opportunity to go deeper inside the subject with more complex observations, on the other hand. We refer to the opportunity to make explicit the dependence of the stick-slip dynamics on the sliding velocity or on the initial conditions, to the exploration of different types of dynamics and their connection with the model, to the possibility of displaying real-time the phase space trajectory and the mechanic energy trends. The use of computer aided sensors allows also to introduce the problems connected with transduction, sampling and numerical calculus, whose implications can also be

observed real-time. During the last months, we used these didactic materials in lab-sessions for both undergraduate students and participants to the teacher training school for secondary education at the University of Naples "Federico II". About 100 people in total were involved. The educational impact is still under evaluation.

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Can indirect supportive digital hints during the solving of physics problems improve problem-solving abilities?

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Abstract

Many students often experience difficulties in solving applied physics problems. The causes of failure can be traced back to a lack of knowledge of the concepts and procedures of physics, or to a lack of strategic knowledge required to solve problems systematically. Many researchers claim that the development of strategic knowledge is just as necessary for solving problems as the development of content knowledge. In order to improve students' problem-solving skills, it might be profitable to know at what time during problem solving the use of hints is most effective: during the solving of a problem or after. In an experiment with fourth-year secondary school students, one experimental group (n = 18) received hints during and after problem solving. Both groups used versions of a computer program to solve a great variety of problems. The control group (n = 23) used a textbook, which contained the same problems. The results indicated that the version of the program providing hints during and after problem solving was the most effective – as measured by a problem-solving post-test – followed by the version which only supplied hints afterwards.

Introduction and research questions

In developing computerized instruction for problem solving, several design issues have to be addressed. The most important design issues relate to the type of problems used, the assumed type of knowledge to be developed (Bransford, Brown & Cocking, 2000; De Jong, 1986; Mestre, 2002) and the instruction content and its timing. This paper addresses the latter issue, in other words, the 'when' question.

The timing of instruction

An important question in designing instruction to develop problem-solving abilities is at what time is support most effective for the development of strategic knowledge and content knowledge, both of which are necessary in solving problems. Supporting students in solving applied problems can be accomplished by giving instructions or examples before the problem-solving process begins, during the problem-solving process or after the students' final answer.

Another choose to be made is for direct instruction (the computer decides when to give support) or indirect instruction (moment of use of support is chosen by the student) (Owen & Sweller, 1985; Albecate & VanLehn, 2000; Anderson, Corbett, Koedinger & Pelletier, 1995).

Inherent to the use of direct instruction is that it needs to be predictable and unambiguous. It is not possible to program all the different solutions possible in the case of complicated problems. These problems with direct instruction can be overcome by using indirect instruction (Mathan & Koedinger, 2005; Mestre, 2002; Reif, 1995; Teong, 2003). One reason for choosing indirect instruction is that the best way to develop problem-solving abilities in novices is to support them with a system that gives sufficient room to develop strategic knowledge that fits their way of learning (Reif, 1995). Students need to acquire a flexible problem-solving strategy with which they are able to tackle different types of problems.

Schoenfeld (1992) is an important proponent of the indirect approach to problem solving. He investigated expert and novice problem-solving behavior. On the basis of his research he distinguished between five 'episodes' in the process of problem solving:

- survey the problem (read, analyze)
- activate student's prior knowledge (explore)
- make a plan (plan)
- carry out the plan (implement)
- check the answer (verify)

Experts and novices differ in their approach to solving problems, novices almost immediately start to work out a poorly defined plan, whereas experts take time to analyze the problem and gather information before making and implementing a plan. Schoenfeld argued that novices need to learn to work through the different episodes more effectively.

Influencing the use of indirect instruction

In the case of indirect instruction the student chooses when to use instruction; however, the design of the program can influence the use of indirect instruction and thus the effect of the program. Although problems need to challenge the students, it is best that the level of difficulty is gradually increased. Besides that, one should not make the level of the tasks too easy. Problem solving can only be learned in a situation where students indirectly have all the information needed at their disposal, but are still challenged (see, for example, Van Heuvelen, 1991 a, b).

Research questions

Based on the research described above, we expect that the timely use of support may be a relevant factor in improving students' problem solving. We assume that when students receive timely support the relevant strategic knowledge is acquired to solve problems. The combination of timely support and help afterwards may further improve strategic knowledge, leading to better problem solving. To test these expectations, two versions of a computer program (Pol, Harskamp & Suhre, 2005) were developed: a version with hints during and after processing a problem, and a version with hints only after processing. A third situation had students working on the same problems, but with sub-questions included, from a textbook with a model answer manual. We intended to answer the following questions:

- 1. Does a computer program with hints during and after problem solving improve students' problem-solving ability more than a computer program with hints afterwards only? (Mestre, 2002; Teong, 2003).
- 2. Do either of the computer programs improve students' problem-solving abilities more than the use of the traditional textbook with sub-questions and model answers? (Van Heuvelen, 1991 a, b).

The computer program

Pol et al. (2005) developed a computer program based on the five episodes of Schoenfeld (1992). In the computer program, students guide their own learning process by choosing problems and hints that correspond with the solution episodes.

In solving a problem, students can choose additional instruction by clicking on a toolbar with short descriptions of different kinds of hints available. The hints in the computer program are structured according to the episodes established by Schoenfeld (1992). The idea is that when students are solving problems in a productive way, they are in fact running through Schoenfeld's episodes. Within each of the episodes, students may encounter blockages in the problem-solving process. By offering hints for each episode, using different solution methods the student can continue the solving process and finish. In Figure 1 we give an illustration of the computer screen as seen by the students. The problem can be found on the left of the screen. On the right a menu with hints is shown.

The hints are: Survey (Schoenfeld's episodes: 'read' and 'analyze'), Tools ('explore') and Plan ('plan'). After answering, students get the chance to check their solution and to reflect on it ('verify'). Students are given three opportunities to check an answer, during which time they can continuously consult the hints.



Figure 1: Task 40 from the computer program PhysHint (originally from Middelink et al., 1998).

The intention of the hints is not only to give help, but also to show the usefulness of these informal methods and to stimulate their use. On the other hand, in the computer program, hints will not only be common descriptions of a certain action, but will almost always be linked to the content knowledge needed for the task. Several researchers have emphasized the need to link strategic knowledge to declarative and procedural, that is, content knowledge (Maccini et al., 1999; Wood & Wood, 1999).

Methodology

An experimental pre-test/post-test randomized group design was used to answer the research questions. The 15 to 16-year old participants (first year upper-level) in the experiment were taken from five fifth-year classes from four secondary schools in the Netherlands with average physics examination results. In each class, students were randomly assigned to one of the three groups.

The procedure followed can be found in figure 2.



Figure 2: Schedule for the procedure of the experiment.

Problem-solving tests

The problem-solving tests consisted of applied problems, set in situations not previously encountered by the students, on topics which had been taught during the previous two years. The subjects of the six tasks of the problem-solving pre-test were distance, velocity and acceleration. The subjects of the five tasks of the problem-solving post-test were forces and torque. When solving the problems in the tests the students were explicitly asked to write down how they *analyzed* the problem, came up with a solution *plan*, and how they *checked their solution*.

Knowledge-base tests

Both pre-test and post-test knowledge-base tests consisted of 20 items, the subjects of which were as follows:

- resultant and composite forces (vectors)
- Newton's first and second laws
- torque

The level of the tasks from the pre-test was taken from chapters used in lower classes. The knowledge-base post-test had a comparable level to the tasks in the program.

Reliability and correlations of the tests

All tests showed a sufficient level of reliability ($\alpha = 0.70$ or higher). The correlation between the knowledge pre-test and post-test was 0.31 (p < 0.05), the correlation between the problemsolving pre-test and post-test was 0.40 (p < 0.01).

Treatment

The subject content that was supplied to all three groups was based on lessons about 'Forces', using the same chapter in the same textbook. In the experiment, all students were offered the same tasks to assist them in processing the information from the chapter. These tasks were all taken from the textbook *Systematic Physics* (Middelink et al., 1998). In total, the students in the experimental group were offered 57 tasks. Students from the control group were also offered stepping-up tasks, which were left out for the experimental groups, thus making 80 tasks available for the students of the control group. Regarding the use of the program, the students from the experimental groups were given brief instructions on how to access the program. The students from the experimental groups were not given any special instruction about problem solving. During the project, data on how the tasks were worked out by the students was collected.

Results

General use of the program by the experimental groups and use of tasks by control group

The average relative number of tasks worked through is comparable for all groups. An ANCOVA showed a difference in relative number of tasks answered correctly between the different groups (F = 8.50, p < 0.001). This means that students working out tasks with the help of the program on average finished a higher number of tasks correctly than students from the control group.

Use of the program by the experimental groups

As can be seen in Table 1, the methods of help used by the students of the experimental group covers the whole range. Of interest is the percentage of 'use of model' for both groups, which is not significantly different (an ANCOVA between both groups, with both pre-tests as covariates and the relative use of the model as the dependent factor gave F = 0.066; p = 0.799), despite students from the During/After group being able to discover many aspects of the tasks to be solved from the hints available.

	During/After group	After group
Group	(n=18) (SD)	(n=18) (SD)
Number of tasks carried out	45.2 (12.8)	46.9 (10.8)
Correct (%)	78.2 (10.5)	81.9 (10.2)
Hints used during process (%)	51.1 (22.5)	-
Survey used (%)	35.8 (21.4)	-
Tools used (%)	36.2 (23.1)	-
Plan used (%)	38.1 (23.4)	-
Model used (%)	41.9 (29.7)	43.3 (27.6)
Total computer time (sec.)	8364 (3312)	7986 (2975)
Average computer time per task	183 (41)	168 (40)
(sec. Per task)		

Table 1: Implementation of the computer program and different episodes.

The issue of whether the use of different kinds of help assisted students in answering more tasks correctly was investigated by means of partial correlations. In these partial correlations the percentage of correctly answered tasks was corrected for the scores on both pre-tests. Table 2 mainly shows the tendency for students to answer more tasks correctly when they use the different kinds of help. Only 'use of survey' contributed significantly to the percentage of correctly answered tasks. There is, however, little difference in the relationship between the different types of help and the percentage of correct answers, as all partial correlations lie around the level of significance.

Table 2: Partial correlations between percentage of tasks answered correctly and the use of the different kinds of help, corrected for both knowledge-base and problem-solving pre-test.

inc	uijjereni ki	inus of neip, co	neelea joi be	nn nnowieuz	e buse una p	noolem solvin	g pre iesi.
		Survey,	Use of	Use of	Use of	Use of	Use of
		tools and/or	survey	tools	plan	model	model (%),
		plan used	(%),	(%),	(%),	(%), n = 18	n = 18
		(%), n =18	n = 18	n=18	n = 18	(group DA)	(group A)
%	correctly	0.35 (ns)	0.43	0.40 (ns)	0.33 (ns)	0.35 (ns)	-0.05 (ns)
ans	wered		(p<0.05)				

Students' test scores and differences between the groups

The average scores on the pre-tests can be found in Table 3. In making an ANOVA analysis of both tests, with the group as the fixed factor and both tests as the independent factor respectively, we found no significant differences (F = 0.160; p = 0.905 for the problem-solving pre-test, and F = 0.069; p = 0.933 for the knowledge-base pre-test, respectively).

Tuble 5. Test scores on pre-lesis una posi-lesis.			
	DA group (SD)	A group (SD)	Control group
			(SD)
Pre-test problem solving (0–60)	32.8 (10.1)	32.3 (9.7)	32.4 (10.6)
Pre-test knowledge (0–60)	40.4 (5.9)	39.6 (9.1)	40.3 (7.8)
Post-test problem solving (0–50)	30.7 (6.1)	26.1 (10.5)	21.9 (8.0)
Post-test knowledge (0–60)	30.6 (7.5)	32.4 (7.2)	31.7 (8.7)

Table 3: Test scores on	pre-tests and	post-tests.
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Did the experimental groups differ after the experiment? As the students, under all conditions, had the possibility to check model answers and learn how to apply content knowledge to solve the tasks, we expected roughly the same amount of domain-knowledge learning in all three groups. An ANCOVA, with the experimental condition as the fixed factor, knowledge-base post-test as the independent factor and both pre-tests as co-variates, showed the difference between the three conditions to be not significant (F = 0.493; p = 0.614). Also, there were no interaction effects between the experimental condition and the domain-knowledge pre-test, indicating that in all three groups students learned the same amount of domain knowledge.

We expected differences on the problem-solving post-test. An ANCOVA with the experimental condition as the fixed factor, the problem-solving post-test as the independent

factor and both pre-tests as co-variates was significant (F = 6.19; p = 0.004), as we expected. There were no interaction effects between the experimental condition and pre-tests on the problem-solving post-test.

To find out if the conditions differed as expected, a Least Significant Difference (LSD) analysis was carried out. The results can be found in Table 4.

Table 4: Pair-wise LSD analysis of problem-solving post-test, with both pre-tests as 'covariates'.

Least Significant Difference	Contrast estimate	Significance
During/After vs After	4.283	< 0.05
During/After vs Control	8.369	0.001
After vs Control	4.085	< 0.05

This analysis confirmed the expectations formulated in hypotheses 1 and 2. The means of group DA and group A on the problem-solving post-test differ significantly and favor group DA. The mean of group A is significantly higher than the mean of the control group. Groups DA and A show about half a standard deviation increase compared to the control group. The gain for the experimental group DA compared with group A is 30.7 - 26.1 / 10.5 = 0.44 std. The measured gain for group A compared with the control group is 26.1 - 21.9 / 8.0 = 0.53 std.

Conclusion and Discussion

Students of both experimental groups processed about the same number of tasks, and spent on average the same time solving tasks with the help of the computer program. The students of the During/After group used one or more hints on average for 51% of the tasks.

The analysis of the post-tests showed a significant difference between both conditions for problem solving, but not for the knowledge-base test. Therefore we can conclude that students supported indirectly by hints during problem solving and model answers afterwards improve their problem-solving abilities more than students who only have model answers available after problem solving. In the During/After group there is a relationship between the number of hints used and the tasks answered correctly. Such a relationship does not occur in the After group between the use of model answers and number of program tasks answered correctly. From this evidence we may conclude that providing model answers after the problem-solving process is only effective when they are part of a total program of help available during and after the problem-solving process.

Looking at the number of tasks worked out correctly, there is a difference between the experimental DA and A groups versus the control group in favor of the experimental groups. Finally, the students of the DA and A groups outperformed the students of the control group on the problem-solving post-test, thus confirming our second question that offering tasks in a more complex way can positively affect the development of problem-solving abilities.

However, this second conclusion has to be put into perspective. The students of the experimental group were using the computer and students from the control group the textbook with model answers. Literature supports the idea that a difference in media (computer versus textbook) may cause a difference in test scores (Clark, 1994; Woodrow, 1998). In using the computer, students might work differently from those working with the textbook. For example, in using the computer program, students filled in their answers, received feedback and were required to try again if their answers were not correct. The students from the control group checked their solutions by comparing their answers with the answers at the back of their textbook. The feedback system provided by the computer could influence problemsolving abilities and cause a difference between the experimental groups and control group, thus demanding further research using the version of the program in which both hints and model answers are left out.

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Monkey Able to Run Away From the Mirror?

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Abstract

We suggest analyzing the well-known problem of the monkey and the mirror that hang from a rope that is looped through a pulley. It is assumed that weights hanging from the rope do not deviate from the vertical direction during motion. This assumption is not discussed on physics lessons, but to keep strictly to a vertical direction during school laboratory experiments is almost impossible. We discuss this problem using analytical mechanics methods in order to compare theoretical and experimental results according.

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1. Introduction

The following task was set at the Physics Competition: "A light elastic rope is looped over a pulley, with a monkey and a mirror counterbalancing each other hanging on the rope ends. The rope and the pulley masses are neglected. The sliding friction on the pulley axis is neglected too. Can Monkey escape from the mirror "?

The authors of the task presume it is impossible. Since the pulley is imponderable and friction is negligible, it can be concluded that tension forces at the rope ends are equal. Therefore, the equal masses of the monkey and the mirror stay in symmetric conditions and, subsequently, they are supposed to remain on the same level opposite each other at any moment of time.

The above reasoning implies an assumption which evidently cannot be formulated and is accepted as obvious. It is considered that both loads can implement vertical

rectilinear movement.

It is difficult to preserve strictly the vertical movement of loads on the pulley, and it is generally accepted to ignore their vibrations when processing lab analysis. What are the consequences of loads vibration on the rope looped over the pulley? The answer is unexpected and, seemingly, contradicts the intuition. The swinging load is descending.

That is why there exists a principal possibility to pull apart the monkey and the mirror to the opposite directions, even under zero friction, zero weight of the pulley, and there is no need to clamber over the rope.

Though apparently it seems a paradox, this effect can be explained qualitatively using tools of elementary physics and described quantitatively within the framework of analytical mechanics. These are the issues discussed hereinafter in the present paper.

2. Didactical Aspects

The setting comprises a light Pasco block revolving on its horizontal axis with negligible friction, a light rope looped over it. Two equal loads counterbalancing each other are hung up on its ends. Let us deflect one of the loads for a $10^{0}-20^{0}$ angle, and, before having let it down, let us apply to the class with a question about what happens further on:

a) Will the load be just swinging?

b) Will the load ascend?

c) Will the load descend?

The most clear-cut reaction was as follows: "The swinging load descends for being effected by the centrifugal force."

Being essentially correct, this explanation bewilders the teacher. The matter is that "centrifugal force" does not constitute a force proper, as set forth in the school course of physics. This force is related to forces of inertia, and it can be considered as an actual force only in the context of non-inertial systems. In our case it is necessary to turn to the estimation system corresponding to the swinging load, which is unusual for the school course of physics which sometimes considers transfers to evenly accelerating or rotating estimation system. It is not clear, what are the advantages of such apprehension or description of the phenomenon. It seems rather preferable to seek for explanations within the framework of the standard approach based of Newton's laws.

As mentioned above, equal gravity forces for their equal masses and equal tension forces of the rope for absence of friction and neglect of the pulley mass are supposed to cause equal acceleration, which is directed upwards of both loads. If the second load ascends, this means that the rope tension exceeds the gravity force. Since acceleration of the swinging load is directed upwards, we encounter with an interesting situation. Two bodies have same acceleration, which is directed upwards, but one body descends and second body ascends. But swinging load acceleration consists of two components. One of them is connected with the descending end of the rope, and it is equal to that of the ascending load, and it is directed downwards. The second component constitutes centripetal acceleration directed upwards, since the swinging load circumscribes an arch. The second part of acceleration, which is directed upwards, is bigger twice, than the first part of acceleration.

3. Experimental Study of Motion

Let us determine the time dependence of the rope end travel. For this purpose a V-scope is used. The load is deflected in the direction perpendicular to the plane of the pulley rotation. Thus, since the vibration plane and the plane of the pulley rotation were reciprocally perpendicular, collision of the load can be avoided.

A typical result of observations is presented in the following diagram.



The first diagram demonstrates the complex character of the loads translational movement, which constitutes a combination of directed drift and oscillatory movements.

The diagram enables to estimate the average velocity, the average acceleration, as well as the amplitude of the oscillation constituent of the mirror movement. The corresponding values are as follows: the average velocity of the loads is 8-12 cm/sec, and the translational movement acceleration is 0.3-0.5 cm/sec². The diagram also provides an indication that the acceleration pole sign is positive.

We can separate the oscillation motion from the translation motion. The second diagram shows the oscillation displacement as a function of time.



The amplitude of vibration is small as compared to the translational movement. The diagram shows that, due to the travel, the amplitude of vibration is slowing down and its period is slightly lengthening out, the amplitude of the oscillating shift is 2-5mm.

Let us remind here that the load was deflected for about 20° . But in case of the load deflection for about 10° and less, the acceleration pole sign may be negative. Slowing down of the loads movement and its further cessation are caused by the fact that the "centrifugal force" pulling downwards is gradually decreasing and finally becomes balanced by the

friction force. In this context the centrifugal force constitutes a product of the load mass and the centrifugal acceleration transferred to the right part of the movement equation.

As a unit of length used in this diagram, the initial distance between the pulley and the swinging load was chosen. In our case the experiment goes on until this distance becomes doubled.

In order to provide a quantitative description of such behavior of the system, it is necessary to exceed the limits of elementary physics.

Quantitative Description of Motion

The objective of the present section is to obtain an effective equation for coordinates of translational movement which is supposed to conform to the results of the experiment, i.e. to describe the drift motion of the loads with imposed oscillations characterized by slight amplitude, taking into account the friction effect. As a starting point, the Second Newton's law describing movement of each one of the loads in the rope direction is referred to.

(1)
$$\mathbf{m} * (\ddot{\mathbf{r}} - \mathbf{r} * \theta^2) = \mathbf{mg} * \cos\theta - \mathbf{T}_1; \qquad \mathbf{m\ddot{r}} = \mathbf{T}_2 - \mathbf{mg}$$

where $T_{1,2}$ are the forces of the rope tension on both ends of the rope. We do not presume here equality of these forces because of the pulley axis friction, centripetal acceleration $r\dot{\theta}^2$ with opposite direction, \ddot{r} describing the rope end shift.

The term with centripetal acceleration is transferred to the right part of the equation (1), and it will act as "one of functioning forces". Since the rope of the Diagram 2 is deflected from the vertical line at angle θ , a gravitation force projection equaling mg*cos θ is acting along the rope. Omitting algebraic transformations for the sake of conciseness, let us register the motion equation for the moving end of the rope. Let us remind that one of the acting forces is the centrifugal one appearing here because of our having transferred the product of the mass and the centripetal acceleration to the right part of the equation.

The summary acting force is expressed by means of a combination of the kinetic K and the potential U energies of the oscillatory movement.

Here μ is the friction coefficient of slipping on the pulley axis.

A way out can be obtained by using methods of analytical mechanics, which means a transfer to formalism "Action – Angle (Phase)". This approach will be discussed in a separate study. Herein, some heuristic considerations are set forth.

Ideally, in case of extremely slight oscillation energy under friction enabling unimpeded motion, due to equation (2) the rope end will move very slowly, and oscillations will hardly differ from those of mere harmonic vibrations, which can be described by means of trigonometric functions.

$$K(t) = E(r(t)) * \cos^{2}(\psi(t)); \quad U(t) = E(r(t)) * \sin^{2}(\psi(t)).$$
(3)

In extreme cases, when the rope length does not change, the energy and the oscillation rate remain constant too, and the phase value equals the product of the oscillation rate and the time: $\psi = \omega^* t$, though in general cases the oscillation rate depends upon the rope length, which, in its turn, depends upon the time.

(4)
$$\omega = \frac{\partial \psi}{\partial t} = \sqrt{\frac{g}{r}}$$

It is generally known that when a mechanic system performs oscillations, while one of its parameters, as, for instance, the frequency rate or the rope length is changing slowly, a certain value labeled adiabatic invariant remains constant. In case of harmonic oscillations it constitutes a ratio of the oscillation energy to the frequency rate [2].

The notion of adiabatic invariant was known to R. Clausius and L. Boltzmann [3]. P. Ehrenfest was the first to realize the importance of adiabatic invariants for the quantum theory construction [4].

As applied to our problem, the constant value is the product of the oscillation energy and the square root of the rope length.

$$\frac{E}{\omega} = \frac{E * \sqrt{r}}{\sqrt{g}} = \frac{E_0 * \sqrt{r_0}}{\sqrt{g}} = \text{const}$$
(5)

Referring to the correlations (2), (3), (5), let us record the effective equation of motion in its final form:

$$\ddot{\mathbf{r}} = \frac{\mathbf{E}_0 * \mathbf{r}_0^{1/2}}{4 \,\mathbf{m}^* \mathbf{r}^{3/2}} * (1 + 3 * \cos 2\psi) - \mu^* \mathbf{g}$$
(6)

Here the small friction coefficient value is omitted in the first item. In general, equation (6) satisfies all the requirements to the effective equation as set forth at the beginning of the section. This equation describes the drift force

$$\frac{E_0 * r_0^{1/2}}{4m * r^{3/2}},$$
(6a)

which is decreasing with lengthening of the rope due to the law $\propto r^{-\frac{3}{2}}$. When this "force" becomes equal to the friction value described by the item

(6b)

the drift stops. Included herein is information related to motion oscillations taking place in addition to pure drift. Prima facie, it seems that the oscillation component

$$\frac{3E_0r_0^{\frac{1}{2}}}{4mr^{\frac{3}{2}}}\cos 2\psi$$
 (6c)

Thus, it seems that equation (6) is supposed to describe considerable oscillations, which contradicts the experiment. On the other hand, considerable oscillations are supposed to bring about the Kapitza effect [5], i.e. to exert an essential impact upon the drift motion. But a profound analysis of equation (6) indicates that the oscillation amplitude value is extremely small, being inversely proportional to the square frequency rate and comprising about one hundredth part of the initial rope length. Under these circumstances the Kapitza effect, within the period of the rope length doubling, happens to be negligible. Equation (6) without the oscillation component can be solved by means analytical methods.



Conclusion

The simple demonstration of an unexpected behavior of mechanical system is proposed. It is possible to use this demonstration for the classical mechanics learning in a secondary school as well as in a university.

The time dependence of the non oscillated weight displacement was determined by an experimental approach using a V-scope. The experimental curve describes a complicated motion. It represents a combination of a driven motion and small oscillations.

The theoretical explanation of this experimental result was realized in a heuristic way. The adiabatic invariant conception was used to obtain this equation. Its solution describes main particularities of the experimental curve.

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University Physics

Identifying Relevant Prior Knowledge and Skills in Introductory College Physics Courses

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Abstract

This article presents results regarding incoming university students' understanding of some basic physics topics included in the secondary physics curriculum. The results show that these students still hold major alternative conceptions on the tested topics, after high school instruction.

Introduction

Science education research has shown that students in science courses held many ideas on scientific phenomena, part of commonsense knowledge, that were obtained in their everyday interaction with the world. These ideas prove to be resistant to change through formal instruction. This has been specially documented in basic and intermediate levels of education, but it is evidenced also in students' difficulties in science at the university level.

Along this line of thinking we planned to measure the conceptual knowledge of incoming university students on a few topics, part of the standard content of high school physics. To facilitate the comparison of local results with those of very distant institutions in a rather simple way, we chose to administer a diagnostic test made up of single response multiple choice questions. The 13-item test was constructed with questions taken from well-known tests developed after the research on alternative conceptions. These tests address characteristic learning difficulties, documented by the Physics Education Research (PER) community. The physics topics covered in the proposed survey have been well studied using qualitative research methods. These studies have established that students understand the questions under consideration based on a rather small number of common mental models. These models can represent naive ways of interpreting the physical world or, alternatively, the proper scientific model, i.e. the mental model based on the accepted physical laws. A well-designed research based multiple choice test should therefore be efficient in displaying this variety of mental models in a given population.

This article reports some partial results from a study involving students attending the University of San Luis and University of San Juan (Argentina), University of Santiago and University of Antofagasta (Chile), Autonomous University of Puebla and Technological Institute of Monterrey (Mexico) and University of Alcalá (Spain). This study aims at comparing the conceptual knowledge of students that have experienced traditional instruction vs. those students that have followed active methods. In this paper we report some partial results describing incoming university students' understanding of some basic physics topics included in the secondary physics curriculum.

Method

Subjects

The diagnostic test was administered to a sample of students attending several of the universities mentioned above: one Argentinean university, two Chilean universities and one Spanish university (Table I), at the beginning of the academic year 2005-2006 before having had any instruction on the measured topics. All of the students had some previous training in physics at the secondary level.

University	N	University studies
Alcalá (Spain), UAH	82	Biology
Antofagasta (Chile), UCN	393	Civil Engineering and Geology
Santiago (Chile), USACH	107	Civil Engineering
		Mathematics Teacher Training,
San Luis (ARGENTINA), USL	60	Mathematics. Physics.
TOTAL	642	

Table I – Students participating in the study

Measurements

To facilitate the comparison of results among different institutions we chose to administer a diagnostic test made up of single response multiple choice questions (SRMC) about the concepts of force, energy, electrostatic interactions and simple resistive circuits. In order to assess conceptual understanding a 13-item test was constructed with questions taken from well-known tests developed after the research of alternative conceptions. Several questions were taken from the Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992), from Determining and Interpreting Resistive Electric Circuits Concepts Test (Engelhardt & Beichner, 2004) and Conceptual Survey of Electricity and Magnetism (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2001). Also, we included a question about force and energy on an incline (Bliss, Morrison and Ogborn, 1988), vertical motion (Watts and Zylbersztajn, 1981) and electric circuits (Osborne and Freyberg, 1991). In the following we report results regarding 5 of these questions, shown in the Appendix.

Results and discussion

The scores (in %) for all options of the physics questions are presented in the following figures.

Question number 7 involves a simple one-dimensional motion at constant velocity, with friction. As shown in Figure 1, only 12% of all the students answered correctly, a figure very close to a random answer. There are not significantly differences between countries or universities. We note that about 1/3 of the total sample of students believes that the force in the direction of motion must be larger than the force(s) opposing motion, a clear manifestation of the non-Newtonian idea that a (net) force in the direction of motion is necessary to keep things moving a constant velocity. Thirty five percent of the class mix vertical and horizontal forces (option e), a very important difficulty that would severely interfere with instruction when teaching Newton's 2nd Law in two dimensions.

Table II – Question number 7. Second Law of Dynamics

7. (FCI 25) A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed " v_o "

The constant horizontal force applied by the woman:

- a) has the same magnitude as the weight of the box.
- b) its greater than the weight of the box.
- c) has the same magnitude as the total force which resists the motion of the box.
- d) is greater than the total force which resists the motion of the box
- e) is greater than either the weight or the total force which resists the motion of the box.

Figure 1. Second Law of Dynamics



Results about the understanding of fundamental concepts such as force and energy are shown on Figures 2 and 3. It is found that 38% of the students pick the "bb" option combination on question number 8. Option "b" is correct for the force question, but not for the one on energy. Only a meager 15% of the students answered correctly the two questions. We interpret that only this small percentage is being able to differentiate between force and energy, an example of the very common confusion between different physical variables.

Table III - Question number 8. Conceptualization of force and energy



Figure 2. Conceptualization of Force



Figure 3. Conceptualization of Energy



The three situations depicted in question number 10 on the very much-studied vertical motion (Osborne y Freyberg, 1985, Viennot, 1979, Watts and Zylbersztajn, 1981, Clement, 1982, Halloun and Hesteness, 1985) confirmed the prevalence of the "force proportional to velocity" non-Newtonian misconception. Only 31% of the students picked the force pointing vertically down in the upward motion of 10.1 (Figure 4), and only the 21% in the cuspidal point situation depicted in question 10.2 (Figure 5). In the latter case about 70% of the population chose the no force option, manifesting the "no motion no force" misconception. Much to the contrary, a fantastic 90% selected the right choice in the downward motion. This may be interpreted as a correct result produced by the misconception "force proportional to velocity".

- 10. A person throws a tennis ball vertically upward. The following questions regard the total force on the ball while is on the air. Consider negligible the air friction.
 - 10.1. *The ball has been thrown and is moving upward*. Which arrow shows the **force** on the ball?



10.2. *The ball is at the highest point of its trajectory. W*hich arrow shows the **force** on the ball??



10.3. The ball is now moving downward. Which arrow shows the force on the ball?









Figure 5. Force and movement. Cuspidal point

Question 11 looks into the ideas that the students have about simple resistive electric circuits. While 38% of the students seems to hold the correct idea of equal current in a series circuit, 32% evidenced the misconception that current wears out in a resistance (Dupin y Joshua, 1986, Gauld, 1985, Osborne, 1981, 1983) and a 13% thinks that current flows in both directions from the battery to the bulb (Figure 6).



11. Four schematic circuits include a battery, a light bulb and cables represented below. Which one represents the flow of electric current best?:







The situation described in question 13 involve two simple applications of Coulomb's Law. The dependence of electric force on charge is recognized by 40% of the students (Figure 7). However, only a 16% of the total number of students understands how electric force depends on charge separation (Figure 8). About half of Spanish students (51%) assumed a dependence of the inverse of distance instead of the correct dependence on the inverse of distance squared. For both questions, a high percent of students (specially Latin American) did not answer.

 Table VI – Question number 13. Electrostatic forces

 13.

 14. Two small objects each with a net charge +Q exert a force of magnitude F on each other.

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Figure 7. Electrostatics forces. Dependence on charge

Figure 8. Electrostatics forces. Dependence on distance



Looking at overall results of our diagnostic test, we can safely conclude that this population does not hold a robust physical framework. Furthermore, we have seen that the answers to a single multiple choice question can be a very misleading measurement of students' conceptual knowledge (case of question 8.1, 10.3 and 13.1). Care should therefore be taken to avoid overoptimistic results if they are based on items that can be answered correctly by incorrect reasoning guided by alternative conceptions. This fact may be very dangerous if the pre-instruction diagnostic is planned and used to program future instruction.

Conclusions and recommendations

The aim of this study was to determine the students' conceptual understanding of basic laws of mechanics and electricity. Our results indicate that the tested sample does not have a working knowledge of basic physics laws: about 50% have serious deficits in interpreting acceleration, and less than 20% understand the relation between forces in a simple one dimensional motion at constant velocity. The situation is similar regarding simple electric concepts: less than 10% of the students understand the functional dependence of Coulomb's Law with charge and distance, and less than 40% can identify the correct representation of the current intensity in a series circuit with a lamp and a battery. These deficiencies are strikingly found, with minor variations, in students of the four universities studied. A closer analysis of the popularity of the different distractors shows that these students still hold, after high school instruction, major alternative conceptions on the tested topics. In sum, the results strongly point to fundamental deficiencies in existing traditional approaches to physics education.

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A SWOT Audit for the Educator Role of the Biomedical Physics Academic within Faculties of Health Science in Europe

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Abstract

Although biomedical physics academics provide educational services in the majority of Faculties of Health Science (alternatively known as Faculties of Medicine) in Europe, their precise role with respect to the education of the healthcare professions has not been appropriately defined nor studied in a systematic manner. This has often led to role ambiguity and role conflict and their associated ensuing effects, role stress and role strain. In order to address this issue we are conducting a research project with the purpose of producing a strategic development model for the role. Central to the study is a position audit for the role which we have carried out via the wellestablished SWOT (Strengths, Weaknesses, Opportunities, Threats) methodology. Internal strengths and weaknesses of the role were identified through a qualitative survey of biomedical physics departments and biomedical physics curricula delivered to healthcare professionals within Europe. External environmental opportunities and threats were inventorized via a systematic survey of the healthcare, healthcare professional education and higher education literature. This paper reports the results of the SWOT audit.

Introduction

Although biomedical physics (BMP) academics provide educational services in the majority of Faculties of Health Science (FHS) in Europe, their precise role with respect to the education of the healthcare professions (HCP) has not been appropriately defined nor studied in a systematic manner. To address this issue we are conducting a research project with the purpose of producing a strategic development model for the role. Central to the study is a position audit which we have carried out via the SWOT methodology. This paper presents some of the SWOT themes.

Research Design

The fundamental research paradigm of this study was practitioner research, the research approach qualitative, and the philosophical perspective pragmatic. The conceptual frameworks guiding the study were:

a) The open-systems model of organizations which emphasizes that role development occurs within an environment (political, economic, social, technological-scientific) and as a response to changes in that environment,

b) The marketing paradigm which emphasizes that in the current higher education (HE) economic climate BMP services will only be requested (and paid for) by HCP because they are perceived as *being of value to them*.

The SWOT methodology (Weihrich, 1982) is a framework that can be used to match the internal strengths and weaknesses of a role to external environmental opportunities and

threats in order to help role-holders strategically position their role. The methodology has already been used extensively in higher education (Dyson, 2004). Internal strengths and weaknesses of the role were inventorized via a Europe-wide qualitative multi-case-study survey of BMP departments and BMP components of HCP curricula. Criteria of choice of sample BMP departments included: level of BMP educator activity, range of health professions serviced, and higher education structure. The total number of faculties studied was 115 and were from all states which were EU members either before or which became EU members on the first of May 2004. The main data collection technique was document analysis. Document analysis has several main advantages in terms of improving the validity and reliability of a study namely: public documents represent data which has been given thoughtful attention by the authors since they are expected to be seen by many people, the technique is unobtrusive and avoids the biasing of responses or observations created by the researcher's presence during interviews and direct observation and as written evidence provides hard data. On the other hand documents may not always accurately describe the current situation. To reduce the effect of the latter only faculties with updated websites were included in the sample. The document analysis was supplemented when necessary with semistructured interviews, e-mail correspondence and direct observation during on-site visits. Results of the pilot case studies were reported by us during a previous GIREP conference (Caruana & Plasek, 2004). Data was collected from web-sites, published documents, curricular materials and textbooks with the help of a purposely designed thematic datasheet which was divided into the following sections: country-university-FHS data, BMP organization-'location within faculty structure'-mission, stakeholder analysis (extent of BMP educator involvement in the compulsory and elective programme modules of the various HCP), analysis of content of present BMP curricula, role expansion opportunities (programme modules which would be enhanced through the involvement of a BMP educator), curriculum development themes within the FHS impacting the BMP role, exemplars of good BMP curricular practice and research carried out by the BMP. External environmental opportunities for the role and threats to the role were inventorized via a comprehensive systematic review of the HE, biomedical and HCP education literature. The synthesizing and formulations of the conclusions were done mainly be the first author of the paper who is himself a practicing BMP educator. Practitioner research has the advantage that the researcher has a thorough knowledge of the context, however bias in favour of the studied profession has to be constantly guarded against.

Results

Strengths of the role:

S1) High level of subject pride

BMP academics have enormous pride in their subject. This is a very positive factor that we have found throughout practically all the universities we have studied and visited. It is a feeling based on an awareness of the achievements of physics throughout the last century, including the achievements in biomedicine.

S2) High esteem for BMP amongst HCP

A common theme among the HCP educational leaders that we have talked to was the high standing with which these professions regard BMP. In the words of one HCP educator:

"Although we are having a lot of difficulties with the quality of the servicing of physics we insist on keeping it in the curriculum as it looks good on our curriculum document and on the cv of the students"

S3) Strong medical device competences

BMP educators have a level of expertise regarding the principles underlying the scientific, effective, safe and efficient use of medical devices which is vastly superior to that of the other HCP. Essential device competences such as evaluation of device specifications, calibration, considerations of accuracy and precision, statistical analysis of data, quality control are second nature to the BMP but often lacking in other HCP.

S4) Strong competences regarding safety with regard to *physical* agents

BMP educators are strongly positioned to teach protection of patients, staff and others from physical agents (e.g., electrical, electromagnetic, ionizing radiation, thermal, laser). Safety measures for protection from these agents are a regular feature of physics laboratories. They are also increasingly a legal requirement in the clinical areas.

S5) Strong research competences

BMP staff have strong research records which make them highly suitable for undertaking clinical research - in particular when the research is biomedical device and modeling based.

S6) Strong scientific norms and values

BMP academics tend to have strong scientific and research norms and values. Such standards of behaviour are becoming increasingly important as the movements for ensuring that healthcare and educational practice become more evidence-based gain momentum. The insistence on rigour in instrument choice, data collection and analysis, which are the hallmark of the physical sciences, have often been sadly lacking in healthcare and education.

Weaknesses of the role:

W1) Absence of a clear mission and role ambiguity

There is clearly a lack of a well-defined, agreed role definition, whilst mission statements are practically non-existent. In the absence of such a definition each BMP educator practices according to his self-perceived role modulated to local expectations. The result is a high level of role ambiguity.

W2) Inappropriate role boundaries

The self-perceived role varies enormously within Europe. In some BMP departments the prevailing perspective is the very general "physics is the basis of all things including all areas of healthcare" paradigm. Such a perspective would appeal to physics audiences but has little meaning to non-physicists who judge content by relevance to future professional practice and who actively demand justification for its inclusion in congested curricula. These BMP educators often set up syllabi which involve a range of topics which is too wide - leading to role overload and shallow learning. We have also encountered the other extreme. Some BMP academics refuse to teach what does not have strictly established legal foundations leading to role underload and impoverishment.

W3) Absence of international networking

There is very little networking between BMP educators at international levels (and in big states even at national levels). Europe is full of BMP educators who work on their own with little feelings of international collegiality.

W4) Absence of harmonization of curricular content

There is no international consensus (and often especially in the larger states no national one either) over BMP content for the HCP. This contributes further to role ambiguity.

W5) Low awareness of importance of educational research

There is a low level of systematic curriculum development and pedagogical research and low awareness of the increased importance being given to quality in HE. As a consequence many curricula are not really clinical practice-oriented and do not address the learning needs of HCP students. Most BMP educators have not yet reacted sufficiently to modern developments in HE and HCP education, such as, integrated vs. discipline based learning, problem-based vs. presentation based learning, outcome competence vs. discipline-based curricula.

W6) Low educator competences

The educator role requires a different set of competences than other academic component roles and many BMP educators lack educator competences. This needs to be addressed if BMP educators are to be able to play an active part in present educational developments in Europe.

W7) Low strategic planning, marketing and publicizing competences

BMP professionals and academics have low planning, marketing and publicizing competences - they are either unable or perhaps unwilling to analyze, develop, publicize and 'sell' their services.

Opportunities for the role:

O1) EU goal of facilitating worker mobility within Europe

Facilitating worker mobility through the creation of a European Higher Education Area involving greater harmonization of HE qualifications and curricula is a major EU goal. The Tuning initiative is targeted to the establishment of common agreed programme outcome competences. The EU Commission is financing the initiative and many HCP networks are being set-up. It is the perfect opportunity for working on the needed international harmonization of BMP curricula.

O2) EU directives

The EU has set out several directives regarding medical devices, safety from physical agents and the use of personal protective equipment. These directives lead to pressure on health authorities for inclusion of corresponding topics within HCP curricula. These issues are all physics based and hence offer enormous opportunities for the role.

O3) Increased awareness of patient safety standards in healthcare

The EC in its 'Luxembourg Declaration on Patient Safety' (2005) recommends that a safety culture needs to be established within hospitals and that a fostering of this safety culture must start from the FHS. Medical devices and protection from physical agents are priority areas.

O4) The rise of the new HCP: HE based programmes, new HCP and expanded roles

Traditionally HCP education within universities catered only for medicine, dentistry and pharmacy whilst the other HCP were catered for by lower level non-degree awarding institutions. This is rapidly changing all over Europe as HCP make a 1st cycle degree the

basic entry qualification for their respective professions. At the same time, these HCP have been rapidly developing their roles into areas involving more sophisticated medical devices. Moreover as healthcare expands new professions are continuously being created. Many new HCP are device intensive and offer new opportunities for the BMP educator.

O5) Increased awareness of occupational safety issues

Awareness of occupational safety is also on the increase and HCP are expected to take responsibility for their own safety and that of colleagues. The inclusion of competences concerning protection from physical health hazards within HCP curricula are a legal requirement.

O6) The explosion in the number and sophistication of medical devices

The rapid increase in the number and sophistication of medical devices coupled with an insufficient level of BMP education within the curricula of the HCP has led to a situation in which hospitals are full of expensive devices, which are often either not used according to recommended protocols or underutilized owing to insufficient competences on the part of the users. The situation is a golden opportunity for the BMP educator.

Threats to the role:

T1) Resistance to multi-disciplinarity in HCP education

Unfortunately in some countries BMP professionals and academics have to work within healthcare organizations which have a history of inter-professional strife. One negative effect of such situations is a resistance to multi-disciplinarity in HCP education. Some HCP insist that they do all the teaching of their own profession themselves (including the physics) even at the expense of reduced standards!

Conclusion and implications

Although the role of BMP educator has various intrinsic strengths which can be exploited, the role has been generally weakened by neglect from role holders who have not practiced proper role balance with respect to their various academic roles - in particular the educator role is sometimes sidelined as a result of an over-emphasis on the discipline research role. However, the opportunities for the role are tremendous and should role holders rise to the occasion a good future for the role is assured. The SWOT themes will in the near future be used as inputs to the formulation of a strategic development model for the role which would ensure its future well-being. The 'absence of international networking' weakness which is so detrimental to the role will be addressed by organizing the BMP educators within GIREP and the EFOMP (European Federation of Organizations for Medical Physics).

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Identifying Relevant Prior Knowledge and Skills in Introductory College Physics Courses

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Abstract

This article presents results reflecting incoming university students' understanding of some basic physics topics included in high school physics curricula. The results show that these students still hold major alternative conceptions on the tested topics even after high school instruction.

Introduction

Science education research has shown that students enrolled in science courses hold many different ideas obtained in their everyday interaction with the world regarding scientific phenomena, which are part of common-sense knowledge. These ideas have proven to be resistant to change through formal instruction. This has been specifically documented at both the basic and intermediate levels of education, but it is also evidenced by students' difficulties in science at the university level.

Along this line of thinking, we planned to measure the conceptual knowledge of incoming university students on a few topics, all part of the standard content of high school physics. To facilitate the comparison of local results with those of very distant institutions in a rather simple way, we chose to administer a diagnostic test made up of single-response multiple-choice questions. The 13-item test was comprised of questions taken from well-known tests developed according to research on alternative conceptions. These tests addressed characteristic learning difficulties, documented by the Physics Education Research (PER) community. The physics topics covered in the survey were well-studied using qualitative research methods. These studies establish that students understand the questions under consideration based on a rather small number of common mental models. These models can represent naive ways of interpreting the physical world or, alternatively, the proper scientific model, i.e. the mental model based on accepted physical laws. A well-designed research-based multiple-choice test should therefore be effective at displaying this variety of mental models in a given population.

This article reports some partial results from a study involving students attending the Universities of San Luis and San Juan (Argentina), the Universities of Santiago and Antofagasta (Chile), the Autonomous University of Puebla and the Technological Institute of Monterrey (Mexico), and the University of Alcalá (Spain). The aim of this study is to compare the conceptual knowledge of students that have received traditional instruction vs. those students that have followed active methods. In this paper, we provide some partial results which describe incoming university students' understanding of some basic physics topics included in high school physics curricula.

Method

Subjects

The diagnostic test was administered at the beginning of the academic year 2005-2006 to a sample of students before having had any instruction on the measured topics at several of the universities mentioned above: one Argentinean university, two Chilean universities, and one Spanish university (Table I). All of the students had received some prior education in physics at the high school level.

University	N	University studies	
Alcalá (Spain), UAH	82	Biology	
Antofagasta (Chile), UCN	393	Civil Engineering and Geology	
Santiago (Chile), USACH	107	Civil Engineering	
		Mathematics Teacher Training,	
San Luis (ARGENTINA), USL	60	Mathematics, Physics	
Total	642		

Table I – Students participating in the study

Measurements

To facilitate the comparison of results among different institutions, we chose to administer a diagnostic test comprised of single-response multiple-choice questions (SRMC) on the concepts of force, energy, electrostatic interactions and simple resistive circuits. In order to assess conceptual understanding, a 13-item test was constructed with questions taken from well-known tests developed according to research on alternative conceptions. Several questions were taken from Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992), from Determining and Interpreting Resistive Electric Circuits Concepts Test (Engelhardt & Beichner, 2004), and Conceptual Survey of Electricity and Magnetism (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2001). In addition, questions were included about force and energy on an incline (Bliss, Morrison and Ogborn, 1988), vertical motion (Watts and Zylbersztajn, 1981), and electric circuits (Osborne and Freyberg, 1991). The results of 5 of these questions, which can be seen in the Appendix, are reported below.

Results and discussion

The scores (in %) for all options of the physics questions are presented in the following Figures.

Question 7 involves simple one-dimensional motion with constant velocity involving friction. As shown in Figure 1, only 12% of the total number of students answered the question correctly, a percentage very close to that of a random answer. There are no significant differences between countries or universities. We note that about 1/3 of the total sample of students believe that the force in the direction of motion must be larger than the force(s) opposing motion, a clear manifestation of the non-Newtonian idea that a (net) force in the direction of motion is necessary to keep things moving at a constant velocity. Thirty-five percent of the students mix vertical and horizontal forces (option e), a serious obstacle that would severely interfere with instruction when teaching Newton's Second Law in two dimensions.

8. (FCI 25) A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed " v_o "

The constant horizontal force applied by the woman:

- f) has the same magnitude as the weight of the box.
- g) is greater than the weight of the box.
- h) has the same magnitude as the total force which resists the motion of the box.
- i) is greater than the total force which resists the motion of the box.
- j) is greater than either the weight or the total force which resists the motion of the box.



Results concerning the understanding of fundamental concepts such as force and energy are shown in Figures 2 and 3. Thirty-eight percent of the students picked the "bb" option combination for Question 8. Option "b" is correct for the force question, but not for the one on energy. Only a meager 15% of the students answered the two questions correctly. We interpret this to mean that only very few students are able to differentiate between force and energy, an example of the very common confusion between different physical variables.





Table III - Question 8. Conceptualization of Force and Energy



The three situations depicted in Question 10 on the much-studied topic of vertical motion (Osborne and Freyberg, 1985; Viennot, 1979; Watts and Zylbersztajn, 1981; Clement, 1982; Halloun and Hesteness, 1985) confirmed the prevalence of the "force proportional to velocity" non-Newtonian misconception. Only 31% of the students picked the force pointing vertically down in the upward motion of 10.1. (Figure 4), and only 21% correctly answered the cuspidal point situation depicted in Question 10.2. (Figure 5). In the latter case, about 70% of the sample chose the no force option, manifesting the "no motion no force" misconception. However, to the contrary, an incredible 90% selected the right option for downward motion. This may be interpreted to be a correct result produced by the "force proportional to velocity" misconception.

Table IV - Question 10. Force and movement

- 12. A person throws a tennis ball vertically upward. The following questions regard the total force on the ball while it is in the air. Consider air friction to be negligible.
 - 12.1. *The ball has been thrown and is moving upward*. Which arrow shows the **force** on the ball?



12.2. *The ball is at the highest point of its trajectory*. Which arrow shows the **force** on the ball?



12.3. The ball is now moving downward. Which arrow shows the force on the ball?







Question 11 looks into the ideas that the students have about simple resistive electric circuits. While 38% of the students seem to hold the correct idea of equal current in a series circuit, 32% evidenced the misconception that current diminishes with resistance (Dupin and Joshua, 1986, Gauld, 1985, Osborne, 1981, 1983), and 13% think that current flows in both directions from the battery to the bulb (Figure 6).

Table V – Question 11. Electric current model





The situation described in Question 13 involves two simple applications of Coulomb's Law. The dependence of electric force on charge was recognized by 40% of the students (Figure 7); however, only 16% of the total sample understands how electric force depends on charge separation (Figure 8). About half of the Spanish students (51%) assumed a dependence on the inverse of distance instead of the correct dependence on the inverse of distance squared. For both questions, a high percentage of students (especially Latin American) chose not to answer.







Looking at the overall results of our diagnostic test, we can safely conclude that this population does not hold a solid understanding of physics. Furthermore, we have seen that the answers to a single multiple-choice question can be a very misleading measurement of students' conceptual knowledge (e.g. Questions 8.1., 10.3., and 13.1.). Care should therefore be taken to avoid overoptimistic results if they are based on items that can be answered correctly using incorrect reasoning guided by alternative conceptions. This fact may be very dangerous if the pre-instruction diagnostic is planned and used to program future instruction.

Conclusions and recommendations

The aim of this study was to determine the students' conceptual understanding of the basic laws of mechanics and electricity. Our results indicate that the tested sample does not have a working knowledge of basic physical laws: About 50% have serious difficulties in interpreting acceleration, and fewer than 20% understand the relation between forces in a simple model of one-dimensional motion with constant velocity. The situation is similar with respect to simple electric concepts: fewer than 10% of the students understand the functional dependence of Coulomb's Law concerning charge and distance, and fewer than 40% are able to identify the correct representation of current intensity in a series circuit with a lamp and a battery. Surprisingly, these deficiencies are found, with minor variations, in students at the four universities studied. A closer analysis of the popularity of the different distractors shows that these students still hold major alternative conceptions on the tested topics even after high school instruction. In sum, the results strongly point to fundamental deficiencies in existing traditional approaches to physics education.

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Teaching Physics to Non-Physics Majors

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Abstract

In the framework of the Bologna reform, universities are given the task of creating new curricula which are supposed to increase the efficiency of the learning process and to better serve the purposes of the students' mobility and program exchangeability.

Within the curricula that include physics courses, it is necessary to create new physics syllabi, appropriate for various combination majors. In this new framework we are often confronted with a drastic reduction in hours allowed for physics instruction while at the same time the basic goal is to still convey to students, even in courses of such reduced extent, the elementary knowledge that, in our opinion, constitutes the natural sciences and technology literacy. As it is difficult to give, in the limited time frame, a survey of all of the classical physics and the introductory notions of the modern physics, selection and rearrangement of topics are necessary.

In this paper we show ways that were followed in the implementation of such selection and rearrangement procedures for "small-sized" basic physics courses designed for different non-physics majors, and consequent dilemmas which will have to be solved. In particular, it is necessary to preserve some basic topics which convey, in the most essential way, the knowledge of physics as well as the philosophy of the physics approach in dealing with natural phenomena and, at the same time, to teach basic quantitative skills required to describe some of the typical topics relevant for a particular major.

Often, students are given separate explanations of the same phenomenon appearing in different contexts in unrelated ways. As a consequence, the same phenomenon is perceived as a number of different phenomena. Therefore we believe that a closer cooperation between different areas is necessary (and possible) in order to achieve a better connection between various pieces of information. In this way, a better efficiency, i.e. a better understanding at a "lower cost" could be achieved.

1. Introduction

The Bologna Reform, which is probably the most far-reaching university reform in recent times, requires from European Universities a reform of their curricula. A set of objectives, such as the promotion of mobility of students and research staff, the comparability and mutual recognition of qualifications (qualifications framework), the establishment of a system of credits (ECTS), improved recognition of degrees, incorporation of the concept of lifelong learning etc., are without doubt important preconditions for making a better use of the institutions of higher education. As knowledge should know no national frontiers, it is important to remove existing barriers and to establish the basis for improved European cooperation. It can already be seen that students and researchers are more mobile, more flexible and more international than ever before which is very important as internationalization certainly ensures the development and modernization of the education system.

The planning of changes is particularly demanding in programs which are related to different subjects, as is the case at the Faculty of Education of the University of Ljubljana. The present programs of study include combination majors like mathematics-physics, mathematics-technology, physics-technology, chemistry-biology, etc. All these majors have physics requirements, which, however, are different for different combinations, since they depend on how important the knowledge of physics is for a particular combination. Of course, combinations that involve physics require more physics instruction, while the emphasis in combinations with technology is on technical application and where biology is concerned, it seems that less physics is necessary.

The design of new curricula and directions of study were among other things determined by two basic requirements

- (a) the possibility of arbitrary connections between subjects (every subject could be connected to any other one, unlike presently), and
- (b) considerably greater choice of electives, which would of course reduce the number of "regular" courses.

In this article we will discuss a redistribution of contents in the formation of new curricula, and the reformation of curricula for physics for non-physics majors. The present consensus is to have two different courses, one for combinations that involve "technology" (like mathematics-technology) and the other one for combinations that involve biology (like biology-chemistry). In the combination mathematics-computer science, a physics requirement has been abolished.

We are not going to get into the details of problems that have accompanied the formation of new programs. We only remind of the fact that one of the results is a drastic reduction of the physics curriculum.

From the point of view of physics we are of course of the opinion that a basic knowledge of physics is essential for any area of natural sciences or technology. This is because physics is the fundamental natural science, on which findings in all other natural and technical disciplines are based and with the help of which they can be justified. Being faced with noticeably shortened time that is available for the introduction of these basics has required a new thinking and a new approach to the formation of curricula and practical realization of the teaching of physics. A new approach should, despite a shorter time frame, give students a knowledge that seems essential for their literacy in natural sciences.

When "rationalizing" the curriculum, the leading thought is to have students learn

- (a) an overview of classical physics with some idea about modern physics,
- (b) basics skills of how to quantitatively deal with problems in natural sciences, and
- (c) basic experiences and skills for experimental work.

The basic idea about how to realize the above requirements is that it is necessary to present to non-physics students a "physics view of the world" (Kranjc, 2006). This means that the number of phenomena presently included in the "repertoire" should be shrunk; a goal of physics instruction is to bring an understanding based on *structures* determined by natural laws, into the multitude of natural phenomena that surround us.

2. Students' input

Student participation in the Bologna Process and promotion of the attractiveness of the European Higher Education Area is also included in the set of objectives of the Bologna Reform. Therefore we thought to be interesting to find out how students view the necessity and the difficulty of certain chapters from the "iron repertoire" of the classical physics. The following questions were given in a questionnaire.

- 1. How would you rate the difficulty of the areas below (the easiest is 1 and the most difficult is 5). Kinematics, forces and Newton's laws, hydromechanics, heat, electromagnetic field, electric currents, wave optics, and geometric optics. Figure 1 shows the answers.
- 2. What time sequence of the above areas would you like the instruction to follow (which should be the first and which should follow)?
- 3. What content would you emphasize the most in physics courses?
- 4. Would you
 - (a) increase the coverage,
 - (b) leave the coverage unchanged,
 - (c) decrease the coverage?
- 5. What proportions of the lectures, quiz sections, lab sections would you like (in hours)? Can you justify your decision?
 - (a) Lectures:
 - (b) Quiz sections:
 - (c) Lab sections:
- 6. How would you rate the difficulty of the subject Physics?
 - (a) Easy,
 - (b) Demanding,

(c) Difficult,

(d) Very difficult.

Describe in words.

- 7. What would make the study of physics easier for you? What changes would you introduce if you could do it for the past?
- 8. How would you rate the usefulness of your mathematical knowledge in physics courses? (Use from 1 for insufficient to 5 for excellent.) Describe!
- 9. What content that you heard about in physics did you find the most and the least useful, which ones did you find essential and which would you eliminate?
- 10. How would you rate the usefulness of the acquired knowledge of physics in your major area? (Use from 1 for insufficient to 5 for excellent.)
- 11. How would you rate the usefulness of the acquired knowledge of physics in the frame of general education? (Use from 1 for insufficient to 5 for excellent.)
- 12. Are there topics from physics and natural sciences that you wanted to learn about in physics lectures but you did not?
- 13. What did you find most memorable in physics instruction (in positive or negative sense)?



Fig. 1: Level of estimated difficulty of topics.



Fig. 2: Level of estimated difficulty of physics (left), suggestions to increase the coverage, to leave it unchanged, and to reduce it.

One can see from the answers that the sequence of chapters is approximately correlated to their difficulty (1, 2). As far as content to be emphasized, students do not have a clear preference (3), and they do not have an idea what they might find particularly interesting in physics (12). A majority of students would (surprisingly?) keep the same scope (4), which is interesting (and encouraging). Regarding the proportion of lectures and quiz and lab sections, students would want relatively more quiz sections, since they feel a need for more solid knowledge and more use of it (5). It is clear that students consider the subject of physics difficult (6). As far as changes are concerned most students mentioned a need for more examples and experiments, homework and in-class questions about notions that are not clear (7). Question 8: average grade 3, question 9: average grade 3, question 10: average grade 3, question 11: average grade 3. Ratings of usefulness does not show particular characteristics, but seem to depend on personal tastes of students. A majority of students answered no to

question 12, and in question 13 experiments were most often mentioned (in a positive way), saying that too much material is covered in a time that is too short.



Fig. 3: Usefulness of knowledge of physics a) in the frame of general education, b) in students' major area.

3. Dilemmas to be solved

In forming new curricula the following general dilemmas occurred due to more severe time limitations.

- 1. Should lectures still cover all the classical chapters, albeit superficially, or skip some chapters and treat the remaining topics more in depth?
- 2. Should topics be redistributed and connected following new criteria? For example, should forces (gravitational, electromagnetic, nuclear, etc.) be treated together?
- 3. Should labs and quiz sections be together, so that students could practice calculation skill in the labs?
- 4. Should one put more focus on "philosophical" questions regarding physics and natural sciences in general, which do not require a "technical" knowledge (calculation and measurement skills), yet they form a "scientific" view of the world?
- 5. Should one focus more on selected "technical" problems through which students learn about the "background" of how physics functions?
- 6. Should one, and to what degree, open the "big themes" relativity, quantum physics, cosmology, physical aspects of biology?

Realizing that as a result of physics instruction one should expect understanding of diverse natural phenomena in the light of a small number of universally valid natural laws, it seems reasonable to make simultaneous connections between different themes of physics (e.g., simultaneous coverage of the gravitational and Coulomb's Law), and yet preserve the division into standard chapters of physics. Students are used to them and they serve as a framework that helps them get oriented in a multitude of concepts. At the same time it is imperative to establish, repeatedly and with emphasis, connections between phenomena from different chapters, and to emphasize analogies between different phenomena and different representations of the same phenomenon. For example, to study charged particles in electromagnetic field it is necessary (still) to know Newton's laws; in mechanics as well it makes sense to give examples from electromagnetism, etc.

Significantly stronger connection between different subjects is of essence. Especially with respect to mathematics, it would be necessary to coordinate not just the coverage in mathematics and physics, but also the timing of particular topics. Mathematics should give more examples of the use of mathematical functions and equations in concrete examples from physics (or other disciplines). All disciplines involved would benefit from that, students would be able to verify the correctness of their perceptions of mathematics and deepen their knowledge in different applied examples.

The connection of physics with chemistry and biology should be much more intense. Beneficial effects of recognizing the same phenomena in different contexts, something that is difficult for students to see as the same (Kranjc, 2006) (e.g., gas laws in chemistry, action potentials in biology), would be useful for both disciplines. Finding connections between different subjects and coordinating would be enriching for both. We will not discuss here "alternative ways of teaching" (Sliško, 2006), especially the idea to leave students much more initiative in discovering physics content and learning how to use the acquired knowledge, and to base the acquisition of knowledge on continuous confrontation of different views on natural phenomena and on the selection of "the best" answers.

It is important to get students used to the idea that they can think *on their own* and act like scientists which they know. Students are often ashamed of "scientific behavior", because it makes them feel ridiculous. However, if ordinary children can imitate soccer stars (they imitate their game with a ball), and if that benefits them, would it not be also helpful for students if they tried to follow example of great scientists in their physics endeavors?

It seems especially important for a teacher to have a "repertoire" of especially interesting themes with experiments which are fascinating for students and which can be used in everyday life as "attractions" at appropriate social occasions. (Sliško, 2006) This certainly makes the learning, and physics as a discipline attractive and increases the motivation of students.

4. Conclusions

In conclusion we want to list some findings regarding ways of improved teaching in conditions of shortened time.

- 1. Deepen the understanding of basic concepts and establishing as "multichanneled" connections as possible between different pieces of knowledge.
- 2. Strengthen the recognition of same kind structures encountered by students in different contexts. The mixing order and the intertwining of contents makes sense. This is difficult, but important!
- 3. Be open to themes and questions that students themselves bring into the classroom. (It shouldn't be a problem if a teacher needs to do some study in order to find a good answer.)
- 4. Nurture a "scientific" way of thinking as the form of thinking about natural phenomena. Accepting alternative ideas from students, treating them seriously and confronting them with the "orthodox" ones.
- 5. Introduce team work.
- 6. Experiments are of key importance, especially the ones conducted by students themselves. Since students remember them better than words, it is a good idea to derive content out of them. It is important, during experiments, to improve their reliability and attention to detail, etc.
- 7. We should not be afraid to devote more time to more general and therefore more basic frameworks, inside which is physics. Even though there may be less time left for technical details, conditions are created in which technical difficulties are more easily resolved.
- 8. It is important to require students to study. Like in sports, the study of physics (or anything else) requires repetition.
- 9. Require homework.

We believe that the subject of physics as a basis of scientific literacy is important enough that every school system will with all care nurture its quality. Knowledge of physics means the most fundamental information about the intrinsic mechanism according to which the world is evolving. We conclude with a quote by R. P. Feynman (1966): "... in spite of the tremendous amount of work that has been done ... it is possible to condense the enormous mass of results to a large extent—that is, to find *laws* which summarize all our knowledge. ... What do we mean by "understanding" something? We can imagine that this complicated array of moving things which constitutes "the world" is something like a great chess game being played by the gods, and we are observers of the game. We do not know what the rules of the game are; all we are allowed to do is to *watch* the playing. Of course, if we watch long enough, we may eventually catch on to a few of the rules. *The rules of the game* are what we mean by *fundamental physics*. ... If we know the rules, we consider that we "understand" the world."

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Models and Simulations as tools in physics learning

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Abstract

We discuss some simple models using Modellus that have been useful in various university courses, spanning from an initial propedeutic course to experimental physics and a simulation laboratory. The different role of models is shown at those various levels of knowledge and expertise. Examples of application of Modellus in more difficult problems, such as the initial value problem giving rise to river meanders and the analogous boundary value problem for the flexural deformation of a long bar, are included.

Introduction

Many freshmen students have defective knowledge and understanding of basic concepts in science and poor mathematics skills. However, most of them are highly motivated and even skilled at using computers and their interest in computer applications can be used to improve their fitness and chances to succeed in their studies, thus helping us to reduce the failure and desertion rates of Science and Engineering freshmen. This paper addresses the use of models and simulations using Modellus, by Duarte et. al., in three settings: 1) a propedeutic course offered before their actual first trimester enrollment, to improve their communication and problem solving skills; 2) our experimental method courses at the second and third trimester where simulations are used as tools to support teaching and promote a better understanding of the model and the data analysis; and 3) a simulation laboratory course at the third trimester, to introduce students to models, their similarities and range of applicability to problems in different fields, including the simulation of meanders and elastic curves. The simulation files are available upon request. In the last part we give conclusions based on our experience.

Simulations supporting problem comprehension and formulation

Lack of comprehension of a problem by students prevents them from successfully translating it into mathematical terms, as a previous step to writing the right equations to solve, and thus reach its answer. The examples in this section exhibit some concrete obstacles impeding the student's progress to the solution and show instances of how simulations, using just the evaluation and graphing capabilities of Modellus, lend themselves to gradually advance their understanding of concepts and problems as well as of the solution methodology.

Problems giving raise to linear equations or relations

The type is well exemplified by the following two problems, taken from Perelman (1970), the first from kinematics:

«As I walked on the sidewalk beside the tram track, I noticed that every 12 minutes a tram passed me, while every 4 minutes a tram went in the opposite direction. How often do trams leave, assumed to be the same, from the terminal station at each end?»

Since no values of the tram and walking speeds are given, most students assume that these are unnecessary for its solution and their attempt to solve the problem fails. Assuming that these speeds are known and constant, one can write the expression for time between two successive trams going either way and work out the algebraic solution, which yields that this *lapse T* is the harmonic mean of the passing to crossing times *independently* of the speeds and further, that *any pair* of speeds with the ratio of (tram speed : walking speed) = 2:1 is associated with any pair of successive passing to crossing times in the ratio 3:1. The simulation just applies constant rectilinear motion and shows that the position of the successive trams going each

way plotted as a function of t are two pairs of parallel lines, that the walker requires different times to intersect, according to their direction of motion. The triangles with horizontal and vertical sides determined by the intersections of the line representing the walker's position with the parallels offer a shortcut to the solution. Figure 1 shows a set of speeds giving a crossing time of 4 minutes and a passing time of 12 minutes, as given in the quoted problem statement.





The second problem deals with mixing solutions with a different concentration:

«Determine the amount of two solutions, one of 3% concentration and the other of 30% concentration, necessary to obtain a 12% solution.»

Here, the amounts of the given and of the desired solutions are not stated. To solve, mass and volume conservation is required. This problem let us recognize that some students do not understand the concept of *concentration*, and they required the instructor's help just to recall and understand the defining relationship between solute volume, solution volume and concentration, and the availability of the interactive simulation to show their relation was a great teaching and learning support, allowing the instructor to apply various strategies and stages to control the solution properties.

Models in the physics laboratory

Our initial experimental laboratories are highly biased towards developing skills and knowledge in metrology and data handling, while keeping most lab activities based on using very simple measuring instruments. Video cameras and electronic sensors are available and used in some classes and computer simulations, allowing the idealized problem to be studied in detail, guide in planning and conducting the experiment, as well as in clarifying the data analysis.

Bouncing ball

The common occurrence of a ball bouncing off the floor is a very attractive phenomenon to study. The simulation helps to recognize that controlled conditions are required to obtain sensible answers, e.g., the value of the inelastic coefficient r, the ratio of velocity after to that before the contact. It also assists students to grasp why the (t, y) graph for balls dropped with any horizontal velocity is always a set of parabolic arcs and its difference from a stroboscopic picture. The simulation considers different values of the inelastic coefficient in the various cases, while keeping, for simplicity, all the other quantities the same allows students to be asked to recover the value of r from the slope in a log (height) vs. bounce number graph.

Lucas-Washburn law

This law addresses the absorption of water by paper and the advancement of the wetting front, which is easily performed experimentally (Fanelli et. al., 1990). The model considers nearly perfect force balance between the wetting force, assumed constant, and a resistive force proportional to position and speed of progression of the wet front, which is easily integrated by separation of variables to yield a power law, namely, *x* proportional to the square root of *t*. Numerical solution is here for the equation dt(x)/dx but not for dx(t)/dt, because the initial condition *x*=0 at *t*=0 gives an indeterminacy for the latter. The simulation here offers students the opportunity to understand the effect in the x(t) and in the log-log plots of a small systematic error due to the fact that the initially measured *x* deviates from the assumed condition.

Models in the Simulation Laboratory

Since 1999, at our Science and Engineering Division we have taught the Simulation Laboratory course as a compulsory subject. Important features of this course are a) attempt to develop students' ability to understand and apply models, and b) to acquaint with symbolic mathematics computer tools. Since many of the examples considered in the course yield quite easily to numerical solution, we have found that using the purely numerical application Modellus is fruitful, enlightening and simpler for students to work with. Examples of the simulation creating an environment in which students can measure and invites comparison with results from the real world experiment, follow.

Pendulum with an arbitrary amplitude of oscillation

The simulation affords a simple way to study outside a physics laboratory the dependence of the period of a (frictionless) pendulum with amplitude of oscillation and gives some training for conducting the experiment because the procedure is the same, namely, to measure the time required for N complete oscillations.

This and the following simulation were provided originally by Ribeiro and Veit (2000), and a graph with phase-space trajectories was added in order to introduce students to this concept and type of representation.

Analysis of the amplitude of a forced oscillator near resonance

Resonance of mechanical, acoustical and electrical oscillators is a very important model, although quite difficult for freshmen to grasp theoretically and to work with experimentally, beyond a qualitative demonstration. In the simulation, the very important effect of a static force and the steady state amplitude of oscillation at different frequencies of the external force are determined in order to graph points of the resonance curve. Easy and quick comparison between the various cases with different frequency is very useful, for which the phase space graph allows a different perspective.

River meanders and bending of an elastic bar

River meanders are the loops formed by the riverbed as it flows downstream. Meanders can be described as curves whose tangent line makes an angle with the river mean axis that is proportional to the sine of the river length (Leopold and Langbein, 1966). The equilibrium shape of an elastic bar under an applied bending moment gives rise to a similar second order differential equation (Feynman et al., 1964). Both equations are similar to the equation of motion of a frictionless pendulum for arbitrary amplitude of oscillation, except that bending is a boundary value problem. However, we have used the initial value problem solver built in Modellus to show most of the interesting features of both systems (some of which may be studied following the guidelines to explore, describe and answer in the *Notes* window of meander.mdl) and, by trial and error parameter adjustment, we obtained very good approximations to the shape of bars with zero deflections at both ends.

Other examples

The logistic model of population dynamics due to Verhulst turns out to be quite realistic with respect to the slowing down of population growth, the attainment of a steady or equilibrium population and the decrease from an initial overpopulation condition. Comparisons with national or world census data for, e.g., the 20th century is quite reasonable and differences

allow for conjectures about the effect of health care and wars to be made. Other simulations that have been found helpful in supporting or developing students' understanding are the superposition of harmonic oscillations giving rise to beats and the numerical solution of ordinary differential equations describing coupled chemical reactions.

Conclusion

Use of simulations helps to pursue deeper and wider understanding of physical phenomena, models and concepts in students, and are a valuable diagnostic tool to test their understanding and preconceptions. Simulations also improve and develop enquiring, observing, experimental and analysis skills and empower the students to conduct and perform better experimental activities. Premade simulations may be very useful to help the less gifted students to better understand problems and to build those skills. In addition, promotion of collaborative and teamwork in class allows the more gifted students to be willing to help their peers.

Simulations are more profitable if flexible didactic strategies are set forth and we are able to identify the class' and individual's needs and respond accordingly. The ability to repeat them as often as needed lends great help to understanding and correcting misconceptions. Resorting and relying in the presentation of simulations should become a wider and more often used practice, even more so in theoretical and experimental classes.

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The Rasch Model - Based Analysis of the Conceptual Survey of Electricity and Magnetism

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Abstract

The Conceptual Survey of Electricity and Magnetism (CSEM) is a well known assessment instrument designed to assess student knowledge of electricity and magnetism, and diagnose difficulties that students have in this domain. CSEM was administered to a sample of Croatian students at University of Zagreb, and the data obtained were analyzed with the Rasch model. In the stochastic Rasch model the interaction of persons and test items is modelled as the probability of persons' success on an item, which depends only on item difficulty and person ability. The Rasch model enables calculation of linear measures for item difficulties and person abilities, which - together with the analysis of their fit to the model - provide important insight in the functioning of the test. The functioning of the CSEM is discussed on the basis of that analysis. The fit analysis revealed problematic functioning of some items (especially item 14), and the analysis of item difficulties suggested important differences in the difficulties of conceptual areas covered by CSEM.

Introduction

The development of the Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2001) was an important step forward in the process of assessing student knowledge of electricity and magnetism, and of diagnosing difficulties that students have in this domain. CSEM covers a large number of different concepts from the domain of electricity and magnetism, but also touches on concepts from mechanics, such as Newton's laws in the context of electricity and magnetism. The overall results of the American college students on CSEM (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2001) indicated that instruction on electricity and magnetism needed improvement. The comparison of the CSEM results of American and Croatian university students in calculus-based physics courses showed that the average difficulty of any conceptual area in CSEM was surprisingly similar in both groups of students (Planinic, 2006). It appears that CSEM is a reliable and valuable tool that can be used to asses student learning in this area. As for any instrument, it is important to analyze and monitor its functioning. The Rasch model can provide insight in both the functioning of the test as a whole, as well as the functioning of each of its items.

The Rasch model

The Rasch model (Rasch, 1960) is a mathematical model for constructing measures based on a probabilistic relation between any item's difficulty (D_i) and any person's ability (B_n) . For dichotomous items the probability of a correct answer can be expressed as

$$P_{ni} = \frac{e^{B_n - D_i}}{1 + e^{B_n - D_i}}$$

The model defines the unit of measurement called logit (logg odds unit).

The construction of measures starts from the estimation of abilities B_n and item difficulty D_i . The first step in estimating B_n is to convert the raw score percentage of correct answers (p) into odds of success (p/(1-p)), and taking the natural log of these odds. The same procedure is applied to estimate item difficulty D_i , using the percentage of students who answered the item correctly. The obtained measures are expressed on the logit scale. The estimates are then iterated against each other until they give a set of internally consistent item and person parameters. Once the abilities and difficulties are estimated, it is possible to calculate the theoretical probabilities for the success of each person on each item, and compare them with the observed scores. The differences between the two are used to evaluate the fit of data to the model (Bond & Fox, 2001). Rasch analysis programs report two fit statistics (infit and outfit) in normalized form, in which their expected value is 0 and standard deviation 1. Using the commonly accepted interpretation, items with infit and outfit values greater than +2 are considered misfitting. Outfit is unweighted estimate of the degree of fit of responses, whereas infit is weighted to give more value to on-target observation.

Methods

CSEM was administered as posttest to 110 students at University of Zagreb in Zagreb, Croatia. The students have completed 4 semesters of calculus-based general physics courses in which the topic of electricity and magnetism has also been covered (in the second semester). The collected data were analyzed using the Bigsteps Rasch analysis program (Linacre & Wright, 1996).

Results and discussion

Figure 1 shows the comparison of the distribution of person abilities in the sample (represented with crosses on the left) with the distribution of difficulties of items in the test (represented with letter I and the number of the item on the right). The most difficult items and the most able students are on the top.

Letter M on each side of the scale indicates the position of the mean of each distribution. Letters S and Q indicate positions of students or items one or two standard deviations from the mean. The common logit scale for both distributions is on the far left side of the plot. The zero of the scale is set at the mean value of item difficulties. It is noticeable that the test is not centered at this sample (the mean ability of the sample is about 0,5 logit above the mean of the item difficulties, meaning that the test was relatively easy for this sample of students). The majority of the items are found in the center of the test while there is obvious lack of items at both extremes of the test. The test could be improved if some of the medium difficulty items were removed, and some easier and some more difficult items added. The ability of a person is best determined with items in the ± 1 logit interval around their ability level, and for students of high and low ability there is not enough items in those intervals.

The functioning of individual items can be estimated from the analysis of the fit of data to the Rasch model. Items that misfit are characterized by the values of standardized infit and/or outfit larger than 2 (Table 1). Another important parameter for estimation of item functioning is item point biserial correlation (Table 1), which can take values from -1 to +1. If the correlation is low, the success on the item doesn't predict well the success of the student on the test. Such item does not discriminate between less and more able students. Good items will have correlation larger than 0,25, but usually already the items with correlation larger than 0,15 are considered acceptable.

Inspection of Table 1 reveals several items which misfit and/or show low correlation with the rest of the test.

Figure 1. Item – person map: person abilities and item difficulties expressed on the same scale.



Item 14 is the item with the largest value of misfit (outfit = 4,2) and no correlation with the rest of the test (ptbis = 0,02). As can be seen from Figure 1, it is also the most difficult item in the CSEM. Item 14 investigates student understanding of shielding effects of conductors. Item 13, which asks about the electric field inside an empty hollow metal sphere, when the point charge q is outside the sphere, shows that students have some knowledge in that area. Item 13 is an item of average difficulty, but possibly because many students have memorized the fact that the field must be zero inside a conductor without actually understanding the underlying mechanism of charge induction.

ITEM	RAW	MEASURE/	ERROR/	INFIT	OUTFIT	PTBIS
	SCORE	LOGIT	LOGIT	ZSTD	ZSTD	CORR.
I 14	28	1.90	0.24	2.0	4.2	0.02
I 24	33	1.62	0.23	0.2	-0.2	0.44
I 20	39	1.31	0.22	-0.5	-0.7	0.42
I 31	44	1.07	0.21	-0.9	-1.1	0.49
I 11	47	0.93	0.21	-0.2	-0.2	0.42
I 27	47	0.93	0.21	-0.5	-0.9	0.44
I 29	49	0.84	0.21	-3.1	-2.7	0.62
I 32	49	0.84	0.21	2.1	2.1	0.24
I 15	53	0.66	0.21	-0.6	-0.6	0.45
I 22	55	0.57	0.21	1.9	1.9	0.26
I 21	57	0.48	0.21	-1.5	-0.8	0.50
I 2	57	0.48	0.21	2.6	1.5	0.20
I 28	58	0.43	0.21	1.9	1.7	0.25
I 18	63	0.20	0.21	2.0	1.2	0.23
I 25	65	0.11	0.21	-0.2	-0.7	0.42
I 13	68	-0.03	0.21	1.0	0.4	0.31
I 30	69	-0.07	0.21	0.4	-0.1	0.36
I 19	69	-0.07	0.21	-0.6	-0.9	0.44
I 10	71	-0.17	0.22	-0.9	-1.3	0.47
I 16	71	-0.17	0.22	0.3	0.7	0.36
I 7	72	-0.22	0.22	-2.6	-2.1	0.59
I 23	76	-0.42	0.22	-1.0	-1.2	0.47
I 9	78	-0.52	0.23	-0.7	-0.8	0.43
I 6	79	-0.57	0.23	-0.3	-0.8	0.40
I 5	80	-0.63	0.23	-0.5	0.8	0.40
I 17	80	-0.63	0.23	0.1	-0.8	0.37
I 8	84	-0.85	0.24	-1.1	-1.1	0.46
I 4	85	-0.91	0.24	-1.4	-1.6	0.52
I 26	91	-1.31	0.26	-0.4	-0.8	0.37
I 12	92	-1.38	0.27	0.4	0.4	0.21
I 1	96	-1.71	0.30	1.0	2.2	0.03
I 3	104	-2.71	0.42	-0.3	-0.9	0.32
MEAN	66	0.00	0.23	-0.1	-0.1	0,37
S.D.	18	0.98	0.04	1.3	1.4	0,14

Table 1. Item statistics in measure order.

The authors of CSEM have noticed (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2001) that distracter A on item 14 has attracted half of the students in their sample (50% of calculus-based students), with another 13% of students choosing distracter B. The majority of the students chose equal forces, with reasoning based at least partly on Newton's third law. The same tendency was also observed in Croatian sample. The large value of this item's outfit was caused by the unexpected correct answers of some students of lower ability. It might have been easier for students who have not fully accepted Newton's third law than for students who expect equal forces to choose the answer which involves unequal forces. The authors of CSEM have also noted a misuse of Newton's third law on this item (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2001).

Item 14. The figure below shows an electric charge q located at the center of a hollow uncharged conducting metal sphere. Outside the sphere is a second charge Q. Both charges are positive. Choose the description below that describes the net electrical forces on each charge in this situation.



A) Both charges experience the same net force directed away from each other.
B) No net force is experienced by either charge.
C) There is no force on Q but a net force on q.
D) There is no force on q but a net force on Q.

The remaining items which misfit are item 2 (infit = 2,6) and item 1(outfit = 2,2; ptbis = 0,03). The content of these two items is quite similar, with the only difference being that I1 asks about the distribution of charge on conductor, and I2 about the distribution of charge on insulator. I1 is, however, among the easiest items, whereas I2 belongs to difficult items. The misfit of both of these items is not very large, but it still suggests that there is a problem associated with them. The infit of 2,6 for I2 is caused by able students who have unexpectedly failed on I2. Student response to I2 indicates that the issue of charge distribution on insulators and consideration of differences between insulators and conductors is not given enough emphasis during teaching. Item 1 is less problematic regarding the outfit value (2,2), but it shows almost no correlation with the rest of the test. A possible interpretation is that the answer to that item required only recalling of a memorized fact and no real understanding. The answer to I2, however, required understanding, and the correlation of I2 (0,20) is much higher than for I1.

Inspection of Table 1 reveals that items 4, 7, 10, 24 and 27, which require application of Newton's laws in the context of electricity and magnetism, all show higher than average values of correlation (0,52; 0,59; 0,47; 0,44 and 0,44 respectively) and therefore also high discrimination. All items in this group, except I4, have medium to high difficulties (Figure 1) indicating that the understanding and application of Newton's laws in the context of electricity and magnetism can present problems even for advanced students. On the other hand, high correlation of these items with student overall success on the test suggests that the understanding of mechanics is an important factor in developing student understanding in the domain of electricity and magnetism.

Conclusion

Most of the items in CSEM function well and form together a directed scale of student basic understanding of electricity and magnetism. The test could be improved by removing some items from the middle of the test and adding more items in the low and high difficulty regions of the test. Some problematic items have been identified (items 14, 2 and 1) which should either be removed from the test or changed. The analysis of a group of items which require application of Newton's laws in the context of electricity and magnetism points once again to the importance of good student understanding of mechanics which also affects student understanding in other physics domains.

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Utilizing Elements of Lean philosophy in course material preparation

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Abstract

At the National Defence College analysis showed that students had attitude and motivation problems concerning science and technology courses. It was claimed that those courses were theoretical and difficult. One answer to these claims was the idea to produce course material which is more focused, coherent and less encyclopaedic in its nature. One of the aims in the project was to produce such a course material which allows students to concentrate lessons without continuously taking notes.

Lean philosophy underlines production simplicity, low production costs, small series, and minimal use of resources without forgetting the "customer's voice". In this project one set of course books was printed using some underlying elements of the Lean concept. Produced education materials consist of thin, compact booklets, which inspired students. All feedback is possible to apply and relevant upgrades are seen in newer series' because of relatively low and controlled material production costs.

It was observed that learning obstacles in the learning process became smaller because of the material itself and partly due to the compact course material outlook. In spite of Lean production philosophy products should be attractive and interesting. Appearance and content of learning material should be qualified. That's why the production process of course material should be controlled and thorough, which on the other hand is the most critical and demanding challenge in this kind of a project.

Introduction

1.1 Aims of military education

The most important skill in the officer's profession is the successful leadership among their troops in a war or equal conditions. Of almost equal importance is the skill to understand and apply modern warfare equipment. This means that knowledge of physics and skills of utilizing engineering principles are needed. The level of skills and the depth of utilization may vary. The basic education period at the very beginning of studies is the best time to refresh and enhance the cadet's skills in mathematics and physics from high school studies. The basic professional education consists of the basic features of ammunition, sensors, navigation, communication and materials.

1.2 Context and problem definition

The commercial material production for high school courses is a well known business. Also books for standardized physics courses e.g. at Finnish polytechnic schools are comprehensive even though the language itself and the student volume limits the marketing volume. To do something for a less standardized course and for a student amount of less than 100 students per year means that nonstandard publishing methods and sources are needed. At the Finnish National Defence College two alternative levels of introductory physics courses were organized for cadets. These were the General basic course of Physics (2.5 cu) and the scientific basic course of Physics (5 cu). The author was asked to lecture at the first named course as a guest lecturer. The feedback data and the inquiry material were gathered from the first divided basic course.

Many students in NDC find science courses difficult and theoretical. The analysis showed that some of the learning problems were connected to motivation or attitude problems. The standard course (general course) did not precisely follow the existing text book, which was aimed for the advanced course [1]. One need was course specific and functional learning

material. These findings explained part of the motivational and attitude problems among students. Motivational problems also linked to the claims of missing reference material. Another finding was that some students were noticed to spending most of the lecture sessions writing down the lecturing material. Other shortcomings were linked to questions like how the course resources and material were arranged. The teacher report clarified this.

1.3 Purpose of the project

A material development project was started to gain generally better results, make the lectures better for learning, and make the course more motivating. The aim of the project was to produce printable and electrically presentable course sensitive lecturing material for the general physics course at the NDC. The key facts in the environment analysis were the following (1) the students at this course were not majoring in physics, (2) the course itself was relatively short, and (3) the introductory physics course at the college level might take some preliminary skills as guaranteed. The curriculum requires that an axiom-deduction type of teaching should be utilized at the given resources. Controlled resource allocation in the area limits the use of wide material production projects. Therefore a Lean-type approach, which underlines customer focus and a strict resource control was selected as a tool for the development project.

1.4 Lean philosophy as a framework

Customer focus and waste elimination [2] during the production process are the key elements of Lean thinking. Production chains are as simple as possible. Controlled production costs are possible with careful resource allocation. Controlled resource allocation on the other hand needs continuous improvement [3,4] possibly because of careful cost allocation. However the Lean philosophy also underlines a demand for perfection [5]. This aim is possible with proper communication channels and co-operation. Lean ideology also underlines individual activity, the ability to motivate team members and good training. Lean production and manufacturing systems are used e.g. in automobile -, electronic - and food production and in aerospace industry and the pharmaceutical field [2,5].

2. Project

2.1 Description of the Project

The extent of the general physics consisted of 110 learning hours of which 64 were lecturing. This meant that only combinations which include light versions of the phenomena and theory components could be used. The material prepared for students would give the model for defining the relevant quantity, and would sometimes end up as a numeric example. The exercise set, and the list consisting of calculator practicing tasks would be given separately. In the curricula the experimentation periods were linked to the military branch school periods.

From the beginning of the project it was clear that immediate interventions were needed. Later on continuous development would mean minor changes and small improvements. In this case all lecturing material was in an electric form (e.g. the course's transparency set). This means that continuous upgrades are an easy and inexpensive task and printed material is easy to renovate for each new course. However normal preliminary work and post lecturing work is still important.

2.2 Project Interventions

This project's aim was to strengthen learning results and motivation aspects in the standard physics course. The main task was raw material production. The course material package consisted of the lecturing transparencies and video projector material, the exercise task set with solutions for exercises, the preliminary course material handout, and the final printed course booklet set. The course booklet set consists of three compact, thin, focused and course specific booklets [7,8,9] which could help students with attitudinal problems.

In the first versions the model answers for exercises were typed to the exercise set. However some students were more convinced if they got a copy of the hand written and drawn answers. Based on this observation the answers were later copied for the students from the lecturer's drafts. However some of the existing questions with their digitalized answers were included to the final book to give a slight idea of the process, which could start from a phenomena and still end up as calculations. This means that at least few of the touchstones [6] are shown.

The selected tool was a word processor program with a TEX type equation editor. The benefits of vector graphics and utilization of Portable Document File (PDF) and Web publishing (html) tools were also used. The Lean method and feedback based preparation required careful time and resource allocation. Demanding parts of the work were done during the teacher's research periods. The work before and after each lecture in the testing phase should also be allocated to the total material production process.

This projects work was made during three cadet courses. The newly produced material was used from the beginning as a part of the lecturing. In the end of the project the material was printed as three booklets and additional lecturing sets. A Few items from the project have been published and the idea of making course or topic specific material at the NDC has continued.

2.3 Applied Lean elements

The Basic Lean idea is to avoid the waste of resources. In this case this meant that resource intensity was moderate during the project. The produced material was not noble, more likely compact, very course specific and suitable for a short course. During the intensive material production period previously made exercises were also utilized.

A Lean project also needs a defined plan which includes at least the following components: definitions, project organization, product development, streamlining, testing and guidelines for continuous improvement. Internal audits and internal evaluations were integrated during every phase. "Waste elimination" means that every process phase is organized as simply as possible. In small units this demand is not a problem. Perfection demand meant that all feedback corrections work was done as soon as possible and good product quality was the aim.

Lean Feature	Applied in the Material Preparation at NDC	Importance or key advantage	
Simplicity	Small production teams, focused responsibility	Good elasticity	
Customers voice	Regular student feedback system	Material for evaluation	
Controlled production costs or "elimination of waste"	Booklet series with low cost- intensity	Easiness to upgrade	
Perfection	Internal evaluations	Content quality	
Demands for continuous improvement	Moderate project costs allows even light revisions from time to time	Modernizations Possible	
Training	Individual and team training	New approaches and creativity	

TABLE: ADOPTED LEAN FEATURES IN THE PROJECT

Customer focus in this project meant a regular feedback system. This concerns also all informal feedback messages from the students and the evaluation team. The idea of continuous improvement was easy to adapt. From Time to time some modernizations are needed anyways.

3. Conclusion and implications

In this project Lean thinking was applied to the learning material production to a certain degree. Some ideas of Lean ideology seem to be suitable to learning material production processes. Lean thinking underlines team work and shared responsibility. However in this

case centralized responsibility was needed too. This leadership covered areas of total coordination, the innovational responsibility, the results and the resource allocation.

A Lean product must also be attractive and inspired. The appearance and the content of the learning material package must be qualified even if the production process is very controlled in areas concerning resource intensity. This means a controlled and qualified Lean adaptation process which on the other hand is the most challenging side of the project. In learning material production Lean is suitable especially to those areas where a customized and course specific series are needed. The Lean concept seems to be suitable for small units, where revisions and remodelling are needed from time to time and these interventions have to be done within a given allocated resource frame. However if proper quality and perfection is the aim, creative and innovative approaches are needed during the whole development process.

The selected strategy was rewarding all the way. At the beginning the new material itself was only satisfactory but still better than previously used common material. At the final stage the students found the material package attractive. Learning obstacles in the learning process became smaller because of the new material itself and partly due to the compact outlook of text books. The produced material was more course specific. The compact course material outlook had a positive effect on student motivation and attitude tasks.

A text book for a refresher type of course must be compact and simple. The content of the book must be introduced shortly and clearly. The text book must be referred to repeatedly during the lessons. Encouragement and an ability to motivate are still needed in education. The lecturer must show how the introduced topics are related with each other. In the learning material selected phenomena must be presented in a way which helps students to understand the theory base. A Few experiments must be shortly presented in the material. It is true that the axiom-deduction type of teaching requires a previously achieved structure of knowledge. In this case a comprehensive mastery of information was gained in the time (and resource) limited course.

Shared resources from the web environment are widely available. Even local small volume language services are coming. Just to name few of the tools: computer simulations for the experimental part, diagnostic tools for students' skills, standardized examinations for the learning results and Wikipedia type dictionaries. The local college oriented quality work may utilize these tools to a wide extent. On the other hand the resources to make local development might not get better. A Lean based approach proved to be one appropriate way to solve specific development tasks.

4. Innovativeness

The Lean ideology is used widely in many production areas. Some features of Lean ideology might be useful and valuable in projects concerning learning material preparation also. Every learning material project has its different and original needs, resource frames and schemes. This on the other hand dictates which elements of Lean thinking are valuable and worthwhile to adapt in each project.

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Teacher Education

Teaching some Temperature Equilibrium Problems to Teacher Training Students (Implementation of an algorithm for solution)

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INTRODUCTION

During several years of teaching in a Teacher Training School we have been able to observe the difficulties that many students have to solve temperature equilibrium problems that involve changes of state. The resolution algorithm of those problems when there are no changes of state is well-known. It is always based on the fundamental equation for temperature equilibrium problems:

$\Sigma Q_{(lost)} = \Sigma Q_{(gained)}$

That is an application in thermodynamics of the most general *principle of conservation of energy* to a temperature equilibrium problem with an interchange of calorific energy between two or more substances until reaching the heat balance in which all involved substances get the same temperature. Thus, for example, if we take an example of calorimetric problems like the following:

"In a brass calorimeter of 240 g, without losses of heat, that contains 750 cm³ of water at 20,6°C, a 100g of gold and copper alloy coin at 98°C is thrown. Then the temperature raises to 21,0°C. Determine the amount of gold and copper that integrates the coin.

DATA: heat capacities (cal/g°C): brass = 0,09; copper = 0,0922; gold = 0,031."

The resolution of the problem could be the following way :

RESOLUTION:

Loss heat:

Coin (alloy): $m_{Au} c_{Au} \Delta t_{Au} + m_{Cu} c_{Cu} \Delta t_{Cu}$

Gained heat :

Water: $m_w c_{agua} \Delta t_w$

Calorimeter (brass): $m_b c_b \Delta t_b$

We can set out:

$$m_{Au} c_{Au} \Delta t_{Au} + m_{Cu} c_{Cu} \Delta t_{Cu} = m_w c_w \Delta t_{w+} m_b c_b \Delta t_b$$

 $(m_{Au}0,031 + m_{Cu}0,0922)(98 - 21) = (750)(1)(21,0 - 20,6) + (240)(0,09)(21,0 - 20,63)$

 $m_{Au} + m_{Cu} = 100$

Solving this equation system we obtain:

$$m_{Au} = 85,16 g y m_{Cu} = 14,84 g$$

The resolution of the problem could be set out establishing a chart where we will represent the processes that take place, the expression of the thermal energies transferred and their respective signs depending on if they lose (negative -) or gain (positive +) heat:

PROCESS	THERMAL ENERGY	SIGN
The gold of the alloy cools from 98 °C to	$m_{Au} c_{Au} \Delta t_{Au}$	
21 °C	Q_1	(-)
The copper of the alloy cools from 98°C to	$m_{Cu} c_{Cu} \Delta t_{Cu}$	
21°C	Q_2	(-)
The water of the calorimeter heats from	$m_{agua} c_{agua} \varDelta t_{agua}$	
20,6 °C to 21,0 °C	Q_3	(+)
The brass of the calorimeter heats from	$m_{agua}c_{agua}\varDelta t_{agua}$	
20,6 °C to 21,0 °C	Q_4	(+)
	$Q_3 + Q_4 = Q_1 + Q_2$	

Table 1

As it is possible to be seen, we obtain the same result but using an algorithm. What we can ask ourselves is if this type of algorithm, modified in some way, could also be used for cases of resolution of more complex problems, such as those in which take place at least one or more changes of state. In these cases the manuals of problems advise to make a rough estimate before coming to the resolution of the problem since "a priori" it is not easy to know between what two temperatures will be the equilibrium temperature, or if changes of state will happen or not. Let us see the following example taken from a Spanish manual of problems (Gullón and Lopez 1974):

Find the final state of the following system: 20 water steam g at 100° C are introduced in a brass recipient, whose equivalent in water is 20 g and in which a 2 842 g of ice piece has previously been introduced at -11° C:

Data:

 m_v : mass of steam = 20 g m_{eq} : equivalent in water of the recipient = 20 g m_1 : mass of ice = 2 842 g t_e : temperature of equilibrium t_h : temperature of ice = -11° C t_v : temperature of steam = 100° C c_w : specific heat of water = 1 cal/g °C c_i : specific heat of ice = 0,5 cal/g ° C L_f : water latent heat of fusion: 80 cal/g L_v : water latent heat of vaporization = 540 cal/g In order to solve the problem with the use of rough estimates method, we would proceed the following way:

Assumption: The final temperature is higher than zero: $t_e > 0$

Loss heat: $Q_1 = m_v L_v + m_v c \Delta t_v = m_v 540 + m_v (100 - t_e)$

 $Q_g = 20.540 + 20.1.(100 - 0) = 12800$ cal

Gained heat: $Q_g = m_{eq} c \Delta t_{eq} + m_h c_h \Delta t_{h1} + m_h L_f + m_h c \Delta t_{h2}$

 $\begin{array}{l} Q_g = 20 \, . \, 1 \, . \, (t_e - (\text{--}11)) \, + \, 2842 \, . \, 0,5 \, . \, (0 - (\text{--}11)) \, + \, 2842 \, . \, 80 \, + \, 2842 \, . \, 1 \, . \, (t_e - 0) \\ = 20 \, . \, (0 + 11) \, + \, 2842 \, . \, 0,5 \, . \, 11 \, + \, 2842 \, . \, 80 \, + \, 2842 \, . \, 1 \, . \, 0 = 230 \, 578,31 \, \, cal \end{array}$

a quick rough estimate calculation indicates that the equation

 $\sum Q_1 = \sum Qg$

can never be fulfilled since even with all the loss heat, still in the most advantageous case, than would be:

 $t_e = 0 \rightarrow 12\ 800\ calories$

value far below to the amount necessary to melt all ice;

 $m_iL_f = 2842$. 80 = 227 360 calories

Which this result indicates is that, in this case, all the water vapour is condensed and part of the ice is melted, so that the final state of the system will be a mixture of water and ice at the equilibrium temperature of 0° C.

The four following cases can occur depending on the initial amounts of ice and steam and their corresponding temperatures:

FINAL STATE	TEMPERATURES	ICE	STEAM
Mixture of water and steam	$t_{eq} = 100^{\circ}C$	all the ice melts	part of the steam condenses
Mixture of ice and water	$t_{eq} = 0^{\circ}C$	part of the ice melts	All the steam condenses
Liquid water	100 °C > teq > 0 °C	all the ice melts	All the steam condenses

Table 2

All it we can be better understood it if we resorted to the water heating curve:



In which each step can be explained as follows:



Energy relationships as water changes phase.

The application of this graph to a concrete problem would be for example:



In it we can clearly see like the latent heat of vaporization $L_v = 540$ cal/g is 6.75 times greater than the latent heat of fusion $L_f = 80$ cal/g, what indicates that by each gram of steam that condenses at 100^aC, 6,75 g of ice can melt at 0^oC. So, we have

$$m_v (L_v/L_f) = 6.75 m_f$$

This allows us to compare the relative masses of steam and ice, starting off of the temperatures of boiling $(100^{\circ}C)$ and melting $(0^{\circ}C)$ in such a way that:

If
$$m_v = 6,75 m_f \longrightarrow t_{eq} = 100 \ ^oC$$

If $m_f = 6,75 m_v \longrightarrow t_{eq} = 0 \ ^oC$

In the other assumptions the equilibrium temperature will be intermediate between those of melting and boiling.

These curves also show that this is not a linear process that can be solved using a simple equation like $\sum Q_{gained} = \sum Q_{lost}$

The linear process for a temperature equilibrium problem without changes of state would be represented in the following chart:



Chart 4

In this case the equation $\sum \mathbf{Q}_{gained} = \sum \mathbf{Q}_{lost}$ can be directly applied

GUIDE OF RESOLUTION OF TEMPERATURE EQUILIBRIUM PROBLEMS

- 1. Identify all the variables using subscripts that distinguish the amounts clearly (ex. C_w for the heat capacity of the water, C_c for the heat capacity of the calorimeter).
- 2. Make a list with all the processes of heat interchange (energy transference) that take place; consider if, in each case, changes in the temperature of the substances occur and if the increases are positive or negative. If a substance experiences a change in its temperature (it warms up or it cools off), the thermal term is $m c (T_f T_i)$, where c is the specific heat corresponding to that substance. If the substance cools off, the temperature difference will be negative $T_f < T_i$. It is necessary to be specially careful in order to identify the correct sign that must be assigned to the changes of state including the "latent heats".

- 3. If, for example, the fusion of a solid takes place, the thermal term is $+ m L_{fi}$ If a substance in liquid state solidifies (for example, the freezing of water), the corresponding thermal term is $m L_{fi}$. If a liquid is vaporized (ej. The boiling of water), the thermal/energetic term is $+ m L_{yi}$. If a apour or gas condenses in the liquid form, the thermal term is $m L_{yi}$.
- 4. Write the expression corresponding to the conservation of the energy principle in symbolic form (without numbers) applied to the case in particular, making sure that a term for each of the processes identified in the previous section exists. Establish the condition of which the algebraic sum of all the terms of the equation is equal to zero. In those processes in which temperature variations take place (all of them except the changes of state), make sure that the terms are expressed as (final temperature initial temperature).
- 5. Solve the equation algebraically identifying the unknown variable.
- 6. Replace the symbols by their numerical values and calculate.
- 7. Make sure that the solution is expressed in the corresponding correct units, with a number of appropriate significant figures and that it turns out to be physically acceptable (for example, the temperature of the liquid water must be between 0° C and 100° C; the final temperature of equilibrium must be neither inferior nor superior to the temperatures of the problem statement). It is even possible to change the result if the terms add zero in the equation of the conservation principle of energy.

RESOLUTION ALGORITHM OF TEMPERATURE EQUILIBRIUM PROBLEMS

It can be summarized in the following table:

	Qg	Qı	
Ice (solid)	$m_i c_i \Delta t_i$	$m_{v} c_{v} \Delta t_{v}$	Vapor (gas)
FUSION	$m_i L_f$	$m_v L_v$	VAPORIZATION
Water (líquida)	$m_w c_w \Delta t_w$	$m_v c_a \Delta t_a$	Water (liquid)
VAPORIZATION	$m_i L_v$	$m_v L_f$	FUSION
Vapor (gas)	$m_i c_v \Delta t_v$	$m_{\nu}c_{h}\Delta t_{h}$	Ice (solid)
	ΣQg	ΣQ_l	
	Rough e		

Table 4

Applying the algorithm represented in the chart to the previous problem we have:

Table 5

	Q_{g}	Qc	
Ice (solid)	-(2842) (0,5)(11) = -15 631		Vapor (gas)
	cal		
FUSION	(2842)(80) =	(20)(540) =	CONDENSATION
----------------------------	--------------	-------------	----------------
	-227 360 cal	+10 800 cal	
Water (liquid)			Water (liquid)
VAPORIZATION			FREEZING
Vapor (gas)			Ice (solid)
	-242 991	+10 800	
	242 991	> 10 800	
Only part of the ice melts	15 631 >		

This scheme with its corresponding variations could be applied to any other equilibrium temperature problems with changes of state. Although it is certain that the complexity of the problem can be increased if the initial temperatures of the ice and the steam are respectively inferior to 0°C and superior to 100°C, the basic scheme of the assumptions algorithm would be same but just adding the terms:

For the steam: $Q_l = m_v c_v \Delta t$ where $\Delta t = t_v - 100$

For the ice: $Q_g = m_g c_i \Delta t$ dónde $\Delta t = \theta - t_f$

Terms that would be added to the corresponding latent heats for their comparison with the opposite values. The proposed algorithm can help the students to understand the complexity of the temperature equilibrium problems with changes of state and to be conscious that when approaching the setting out and resolution of them, the following simplification cannot be directly applied:

$$\sum Q_l = \sum Q_g$$

In case there are no changes of state, the chart could be simplified the following way

	Q_{g}	Qı	
FUSION (Melting)	0	0	VAPORIZATION
Water (liquid)	$m_w c_w \Delta t_w$	$m_v c_w \Delta t_w$	Water (liquid)
VAPORIZATION	0	0	FUSION (Melting)
	ΣQ_g	ΣQ_l	
	Q_g		

Table 6

If there were only a change of state (for example melting):

Table 7

	Q_{g}	Qı	
FUSION (melting)	$m_i L_f$	0	VAPORIZATION

Water (liquid)	$m_w c_w \Delta t_w$	$m_v c_w \Delta t_w$	Water (liquid)
VAPORIZATION	0	0	FUSION (Melting)
	ΣQ_g	ΣQ_1	
	Rough		

RESOLUTION DIFFICULTIES

The main difficulties for the students when solving problems of temperature equilibrium with changes of state, come from the fact that they apply without revision or analysis the learned algorithm. This is really showy in that kind of problems when the students are not able to see clearly the necessity of a previous and exhaustive analysis of the contextual conditions of the problem. That is to say, if the departure data of it exceed the limits of existence of water in liquid phase between 0 °C and 100 °C in which the equation:

$$Q_g = Q_c$$

is valid:

Therefore, they must take into account if there is or can have one or more changes of state and the terms corresponding to the latent heats $m_f L_f$ and $m_v L_v$.

CONCLUSIONS

- 1. Students, in general, and teacher training students, in particular, have great difficulties resolving temperature equilibrium problems with changes of state.
- 2. These difficulties mainly come from the fact that they try to approach that kind of problems applying an easy and simplified algorithm of resolution based on the known equation $\sum \mathbf{Q}_{gained} = \sum \mathbf{Q}_{lost}$ without taking into account changes of state that can occur during the process established in the problem.
- 3. The most common cases involve water and its changes of phase as the main substance
- 4. The majority of authors recommend make some kind of assumptions, establishing possible final values for the temperature. Thus, students must check if the final answer is consistent with the assumption or is a nonsense.
- 5. The algorithm-chart we propose can help the students to make the right decisions
- 6. The kind of assumptions are as follows:
- a) All the ice melts and $T_f > 0^{\circ}C$ or
- b) $T_f = 0^{\circ}C$ and only part of the ice melts.
- c) All the steam condenses and $0^{\circ}C < T_{f} < 100^{\circ}C$; or
- d) $T_f = 100^{\circ}C$ and only part of the steam condenses
- 7. Using heat curves can also illustrate the students to assume that these cases are not linear and do not respond to a simple equation like $\sum Q_{gained} = \sum Q_{lost}$

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Training non-graduate Secondary School Laboratory Assistants

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Abstract

We report on a course for "Secondary School Physics Laboratory Assistant" education, managed by Milan University. The one-year course is based both on disciplinary theoretical contents and on practical laboratory activities. The significant part of the discussion deals with relevant aspects arising from the students' profile, their initial competence, the quality of their laboratory reports. The improvement of the students' progressive scientific knowledge is also interesting, along with the developing understanding of theoretical concepts of data interpretation related to the experimental activity. This is a crucial condition for a positive interaction between "Technical Laboratory Assistants" and Teachers in Physics Education of Secondary School Students.

1. Background

In the academic year 2005/06 the Università degli Studi di Milano promoted the professional training of a group of technical teachers for Physics Lab lessons (Insegnante Tecnico Pratico or I.T.P.). I.T.P.'s are present in technically oriented high schools; the required qualification is only an engineering high school diploma, but further theoretical and technical additional competence is necessary. They are responsible for lab activities and for the assessment of the students' practical skills in the lab, as well as for their lab reports. Currently, in the province of Milano, there are 69 I.T.P.'s assisting 183 Physics teachers.

I.T.P.'s have been working in Italian schools since 1948 [1]. Up to the early '90s they were taken on first by the school principal himself, and then by the provincial education office. After that, prospective candidates had to sit for public examinations at a regional level, which shortly thereafter developed into public examinations open only to candidates who had attended a 150-hour training course, given by university graduated Physics teachers with extended high school teaching experience. In February 2005, for the first time, the Minister of Education [2] entrusted Universities with the professional training courses for I.T.P.'s.

2. Structure of the course organized in Milan

The Milan section of "Lombardy Inter-University School for high School Teaching" (SILSIS-Mi) held a training course for 12 future I.T.P.'s in Physics, lasting from October 2005 to April 2006.

The course consisted of 500 hours, 300 of which dealt on theory lessons and the others 200 were devoted to laboratory and teaching methods. Attendance was mandatory for 70% of the total time. The theory lessons included teaching modules on specific subjects, of at least 10 hours each and they were strictly related to the corresponding lab modules. On-line activities were also included.

3. Contents

The course modules can be grouped into three classes. The first one includes the specific submodules related to a) elementary Physics with lab (80 hours), b) basic notions in modern and atomic Physics with lab (64 hours). The modules on didactic and pedagogical themes about Science of Education (100 hours), Mathematics (50 on line hours), computer methods for Physics (24 hours), planning of teaching paths (24 hours) belong to the second class. The third class consists of supervised teaching practice in selected schools (100 hours). Finally, 58 hours are devoted to laying out a final report to be discussed during the final oral examination.

4. Initial situation

At the very beginning, students were requested to fill up a questionnaire to collect information about their use of a laboratory, type of degree they were awarded, their skills in the use of a computer, and their teaching experience.

Only two out of the 12 students, aged between 30 and 50, who took part in the course, had a university degree, but none of them in Physics. All of them had been awarded leaving diplomas from technical high schools. Most of them had taught Physics lab for more than 4 years, but they were very far from mastering key tools for their activity as teachers in a Physics laboratory. Two of them seldom worked in a Physics laboratory.

As far as computer science was involved, they soon showed difficulties both with data handling and with Internet surfing. Most of them were unable to select relevant information and to connect and ponder facts and figures, to analyze and evaluate computer software according to its contents and technical characteristics.

Furthermore, the initial theory lessons immediately showed that the students had a poor background, both in Physics and in Mathematics. Not only did they lack the necessary robust background that Physics graduates have in this subject, but also, in some cases, a sufficient basic preparation. Besides, they seemed to be unable to fill in the gaps in their personal competence by themselves and to update their general knowledge in the subject and in teaching methodology.

5. Initial knowledge in Physics

The students were asked to list the lab experiences they had performed in the schools where they had been working. They were then asked to choose at least one experience in their list and to describe it qualitatively. Finally they were asked to mention some physical principles connected to the experience described.

The results were the following:

• Only one student out of 12 had been able both to give a complete description of the chosen experiment and identify the related physical principles. Two students were able to identify the fundamental aspects but their description was far from being complete. Three students wrote nothing and the remaining 6 could not focus on fundamental aspects and made conceptual mistakes.

• Even experiment descriptions, which were almost complete, seemed to be mere "operating instructions".

• Sometimes the description was so minimal as to appear almost meaningless.

• We noticed an improper use of technical terms and a strange "meaning" given to Mathematics. The students appeared not to understand the difference between a Math formula and a physical principle.

• The students hardly distinguished the mere description of a physical phenomenon from its modeling.

6. Our choices

After a careful evaluation of the preliminary test and also because of the students' initial distrusts and concerns, we opted for an approach relying on the students' professional experience through a constant link between theory and lab experiences [3]. Care was taken to repeatedly review the necessary Mathematics formalism before using it in specific Physics problems.

We decided to present the subject matter starting from the description of significant experiments, analyzing the experimental apparatus, the realization of the experiment itself, the aims of the experience and the relevant physical principles.

Classical and modern Physics were treated at a pre-university level, and, whenever possible, either performing or describing in detail experiments usually performed in high schools or in university elementary Physics courses.

The interpretation of data and the error theory were given particular attention in each module.

At the light of the results obtained, and after the students' comments (see section 9), the chosen approach has proved particularly effective.

As for the module on "teaching paths", it included representative examples of the actual planning of Physics lessons for high-school students, focused on lab experiments, through the consideration of the following points:

• The key points of the theory;

- The necessary background;
- The aims of the presentation;
- The actual lab experiment.

The module "Computer methods in Physics", very similar to the one planned for graduate students who attend SILSIS-Mi to become Physics teachers, was based on a critical use and analysis of Internet sites and software packages concerning Physics [4].

7. Final results

At the end of the theory part of the elementary and atomic Physics modules (that is 4 months since the beginning of the course) the students were presented with a final questionnaire (this was done on the last day of lesson, without any previous warning). This questionnaire, just like the initial one, asked for the description of a lab experiment.

We compared the results of the two tests, being evaluated on the following evaluation scale:

- 1. minimum level: both fundamental and secondary aspects were neglected
- 2. fundamental aspects were neglected in favor of details and/or secondary aspects
- 3. the essential aspects were treated in good details
- 4. maximum level: the question was answered in full

Fig. 1 shows the students' grades.

The results show an outstanding net improvement. From an analysis of all the students' performances, we can conclude that:

• Almost all of the students were well above pass level (two students decided to take the final examination in the next session, so as to have more time to study);

• The students have widely proved that they now have an understanding of the basic Physics notions, even if they still have problems in expressing them (their vocabulary was not always appropriate);

• Even if they do not yet master all of the relevant theory, all the students have learnt to fit the single lab experiments within a well-patterned frame of relevant theoretical knowledge, and to understand their relations.



Fig. 1 Comparison of the students' grades before and after the first term of the course

8. Final examination

At the end of the course, in June 2006, after a final examination, students were awarded the qualification of "abilitazione all'insegnamento", i. e. the official qualification necessary to work in a Physics lab of particular Italian secondary schools.

Half of the final grade (a maximum of 40 points out of 80) came from the results of four intermediate tests, based on the contents of one or more modules (Fig.2). The remaining 40 points were assigned through a final test, which consisted both of a written and an oral examination each carrying a maximum of 20 points (Fig.3 and Fig. 4). At least 56 points was the minimum acceptable grade. From the graphs we can say that:

• More than 50% of the students produced a very good final report (Fig. 4);

- During written test only one student had minimum evaluation, the other results are homogeneously distributed (Fig 3);
- Due to the above mentioned reasons, the distribution of the final results (Fig.5) is very similar to the one of students' average results in intermediate tests (Fig. 2).



Fig.2 Average results in intermediate exams





Fig.3 Results of final written examination

9. Course validity

At the end the students were given an anonymous questionnaire and they were asked to express their personal opinion about the course (Figs. 6 and 7). The students appreciated working in groups and their being directly involving in lessons. We gathered some critical observations as well, particularly as far as the rhythm of the initiative was concerned (for them it was too fast).



Evaluation scale



10. Conclusion

To improve the students' (ITP) initial professional know-how (extremely poor necessary theoretical background), it was necessary to pay attention to the following crucial points:

• the problem of adult education and therefore the necessity of introducing particular educational methodologies;

• the importance of encouraging and supporting the students' previous experience.

We obtained satisfactory results from different points of view:

- the improvement in the knowledge of Physics;
- the capacity of performing a good laboratory report;
- the increasing ability in the use of the computer and in analyzing how useful it is in teaching nowadays.

Some of the students asked us to keep contacts with the Physics Department showing, above all, that they understood the importance of updating.

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Modelling Cell Radiosensitivity for Pedagogical Purpose

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Abstract

Ionizing radiation has proven to be a double-edged sword: it is a potent mutagen and carcinogen, and it is also used in the diagnosis and treatment of cancer. The key issues that explain and sustain both situations are the same: radiation damage to DNA, DNA damage repair mechanisms, cell-cycle kinetics, linear energy transfer effects, oxygen effects, genomic instability, neoplastic transformation, and apoptosis. With a difference: concepts are modeled to account for opposite purposes and explanations. Truths that make up a valid argument for carcinogenesis need to be reframed to account for therapeutics. In the present work we argue that the spatiotemporal reasoning tools of physics can help to enhance the understanding of the effects of ionizing radiation at the molecular, cellular and whole-tissue levels. Our aim is to translate to science education -through teachers' in-service training- some results from the field of cancer research. We explore the case of cell radiosensitivity for two reasons: first, radiosensitivity has emerged as an actual question for a local group of secondary school teachers working in a science project in Brazil, who have expressed their concerns with the valid idea that mitotic -not phase S- cells are most sensitive to ionizing radiation; and with the idea that observation of cells with the feature of apoptosis is not necessarily indicative of cell radiosensitivity. Second, from the perspective of the logical organization of categories, cells are basic-level categories from which we can either dig for more specialized molecular knowledge, or abstract towards whole-tissues.

Introduction

Ionizing radiation has proven to be a double-edged sword: it is a potent mutagen and carcinogen, and it is also used in the diagnosis and treatment of cancer. The key issues that explain and sustain both situations are the same: radiation damage to DNA, DNA damage repair mechanisms, cell-cycle kinetics, linear energy transfer effects, oxygen effects, genomic instability, neoplastic transformation, and apoptosis. Apoptosis, or programmed cell death, plays a role in more than one of the above mentioned factors. Because it is known to occur in cells irradiated *in vitro* and *in vivo*, the more obvious role is that apoptosis could account for cell radiosensitivity. But evidence from research is controversial.

In the present work we suggest that both basic image schemata as proposed by Johnson (1987) and basic level categories as conceived by Lakoff (1987) that extend preconceptual bodily experience to incorporate cognitive mapping structures, can help to model an understanding of the complex issues that account for the effects of radiation, in a way understandable to a science literate person. The work is part of an ongoing project that seeks to translate to science education –through secondary school teachers' in-service training-some results from the field of cancer research. Our epistemological perspective squares with that adopted by the Public Understanding of Research (PUR) effort launched by the National Science Foundation (Field & Powell, 2001). This implies a commitment to a position that values arguments with a basis on epistemic justifications for issues and claims that give insights into the process by which the research direction is altered by new data.

We explore the case of cell radiosensitivity for two reasons: first, radiosensitivity has emerged as an actual question for a local group of secondary school teachers working in a science project in Brazil, who have expressed their concerns with the valid idea that mitotic – not phase S- cells are most sensitive to ionizing radiation; and with the idea that observation

of cells with the feature of apoptosis is not necessarily indicative of cell radiosensitivity. Second, from the perspective of the logical organization of categories, cells are basic-level categories from which we can either dig for more specialized molecular knowledge, or abstract towards whole-tissues.

Radiation-induced Cell Death

Along history, radiation-induced cell death has been attributed to different kinds of mechanisms. Reproductive cell death, a kind of death expressed when a cell fails to divide successfully, was initially proposed as part of a model system for the study of relationship of basic cellular processes that modifies radiation response, such as DNA damage and repair mechanisms. In reproductive death, radiation initially produces DNA damage. The residual unrepaired or misrepaired DNA damage results in chromosome aberrations and genomic instability, and these persistent lesions eventually lead to cell death in a progeny, usually after several mitotic cycles (Held, 1997). The clonogenic assays for cell survival using culture mammalian cells has provided, since the work of Puck & Marcus (1956), the experimental basis for characterizing this mode of death (Meyn, 1997). In a clonogenic assay, parallel dishes are seeded with irradiated cells that increase in number. The colonies counted divided by the number of colonies plated plus a factor that corrects for the platting efficiency gives the surviving fraction.

Squaring with this model, researchers have established tumor cell radiosensitivity (the relative susceptibility of cells, tissues, organs or organisms to the harmful effect of ionizing radiation) as a property related to the position of tumor cells within the cell cycle (Figure 1). Deductions from cell survival curves (cell survival data plotted as logarithm of the surviving fraction versus dose) suggest that the late G2 and M phases are the most radiosensitive, whereas the late S phase is the most radioresistant. Chromatin in mitotic cells has been found to be more susceptible to radiation-induced DNA strand-breakage than



Fig. 1: Cell cycle

the dispersed chromatin of interphase cells (Stobbe *et al.*, 2002). This knowledge is rarely treated in secondary and undergraduate schools, and not evoked by secondary school teachers when trying to explain radiosensitivity (data from our project).

Apoptosis has been proposed as a second mode of cell death. This mode was first described by Kerr *et al.* (1972). Radiation-induced apoptosis occurs before the first post-irradiation mitosis and is abundant. It appears to be a feature of cultured cells of hematologic or lymphoid origin, contrasting with fibroblasts and cultured cells of epithelial origin that tend to undergo reproductive cell death and a secondary kind of apoptosis that appears much late after irradiation. Since the early 1980's, the presence of apoptotic bodies has also been measured in irradiated salivary glands and in the epithelium of intestinal crypts following irradiation. These cells undergo a very rapid (within hours) cell death, prior to the first postirradiation cell division. In these cell systems, apoptosis can be induced by doses of 5 Gy or less, a fact that some researchers have used as an indication of a high radiosensitive. It is not easy to assay for apoptosis. Some methods exist, but they usually underestimate its total amount, as they measure apoptosis only at a single point in time (as morphology-based assays) or only up to the time of the assay (as DNA fragmentation assays).

The interpretation of whether apoptosis or reproductive cell death is the main mode of death is still a matter of debate. In some cases, the relationship between radiation sensitivity as assessed by clonogenicity and by apoptosis become quite closer, but as pointed out by Olive *et al.* (1996), more apoptosis does not explain greater radiosensitivity. Also, loss of clonogenicity only requires that cells stop dividing, not that they cease to exist, which means

that there is no need to invoke apoptosis to explain the loss of clonogenicity in cells that undergo permanent growth arrest (Held, 1997). Apoptosis is the mode of death most emphasized in secondary and undergraduate school. The above mentioned teachers' tendency to attribute to the dispersed chromatin of interphase cells –phase S- the highest sensitivity is accompanied with a supposition that apoptosis is the only event involved in cell radiosensitivity.

According to Hendry & West (1997), both apoptotic and mitotic cell death are likely to contribute to target cell killing and hence to tissue reactions after irradiation. However, their relative contributions do not seem to follow a general rule. It is more likely that they are cell-type dependent.

We propose that a profitable way to clarify the concept of cell radiosensitivity in its full meaning is to look more closely at a particular cell/tissue case for which both kinds of death are important. The intestine epithelium is an interesting one: the cellular and molecular transformations from adenoma to carcinoma are well established; alternative models of morphogenesis exist in which images of the propensity to apoptosis, and the reproductive cell death, have a role; and the intestine has shown to be more radiosensitive than most non-hematological tumors. In the remaining of the paper we present an approach to model conceptually the nature and behavior of normal and neoplastic intestine as conceived by contemporary research. Arguments about radiosensitivity are inferences made from these models. Basic structures of inferences are important to clarify.

THE Conceptual Modelling Approach

Our modelling approach has two components: Toulmin's Layout of Argument and a conceptual framework for selecting a group of arguments of cognitive and informational interest. Both take argumentation as structures able to capture more than classical logical relations: the Layout applies to ordinary discourse, certainly more fuzzy and complex than a network of syllogisms; and the conceptual framework sees logical inferences and understanding as constrained by image schemata and metaphorical projection.

Toulmin's Layout (Figure 2) has been largely used in the science education arena in evaluating students and teachers' discourse and in helping them to structure their explanations within standards acceptable for classroom science.

Fig. 2: Toulmin's Layout



(D) is the ground that supports the arguer's (C), while (W) is the means by which (C) relates to (D), on the basis of some (B). Mediating between (C) and (D) is the possibility of (Q), so that in certain circumstances and/or in certain conditions, the relationship between (C) and (D) can be adjusted. Finally, (R), describing exception to (W), might be included to challenge the relationship between (D) and (C), either helping to reinforce the relationship between (D) and (C), either helping to reinforce the relationship or challenging it to change (and, for example, be qualified).

In the present work it is used as a framework for identifying and extracting researchers' arguments from a group of selected papers. The intention is to capture, from the universe of those image schemata that confer ontology and structure to the network of entailments of the community discourse, the most characteristic structures of inference. For that matter, propositions expressing terms characteristic of spatial-temporal reasoning (WHERE, WHEN, HOW LONG, HOW MUCH, HOW MANY) were extracted from the papers for three main issues: stem cells in the intestine; apoptosis in the intestine, and radiation-induced apoptosis. Propositions were marked according to levels: cellular (green), molecular (blue), and tissue/organ (red). Some of them were accompanied by features of explanations (HOW and WHAT) and action/agency (PROCESS, FUNCTION, CAPACITY, BELIEF). The Appendix

exemplifies the nature of results for "stem cells in the intestine", "apoptosis in the intestine", and "radiation-induced apoptosis".

MODELS FOR THE INTESTINE

Three models for the intestine were described: normal intestine (Figure 3), normal irradiatedintestine (Figure 4), and adenoma (Figure 5). They were constructed from information and assumptions present in the extracts. Based on these models, three kinds of stories can be read, corresponding to the three levels marked in Table 01: cellular (green), molecular (blue), and tissue/organ (red). These constitute a first kind of contribution to science education, as they resemble a simplified systematic analysis that can be read and understood by a cultured secondary school teacher in in-service courses.

The comparison for cell death assayed by apoptosis and by loss of clonogenicity in the case of the intestinal cell radiosensitivity conducted by Hendry & Potten (1982) represents the most inclusive explanation for the relation between apoptosis and cell radiosensitivity, from which inferences can be drawn from these models. Apoptosis, in irradiated intestinal cells, represents a sub-population which is very sensitive to an early apoptotic death, but which is part of an equally-resistant population when clonogenicity is considered.

Fig. 3: Normal Colonic Mucosa

(From: http://library.med.utah.edu/WebPath/GIHTML/GI115.html)



Fig. 4: Normal Irradiated Intestine (From: SHINOMIYA, 2001)



5:

(Adaptation from <u>http://library.med.utah.edu/WebPath/GIHTML/GI115.html;</u> Shih, 2001; and Strater, 1995)

Fig.



STRUCTURES OF INFERENCES

According to Johnson (1987), abstract inference patterns are the result of metaphorical projections of image schemata of different kinds. In our data, the following schemata were predominant: path, cycle, scale, link (coupling of physical objects, temporal connections, and genetic connections), iteration, balancing, near-far, merging, contact, container, enablement, blockage, restraint removal, mass-count, part-whole, and process.

We suggest two models that can be used to explain radiation-induced apoptosis (work in progress): *moving-crowd* (like the flow of electricity, similar to Gentner and Gentner, 1983); and the *dying-crowd* (like the evaporation of a liquid). As tools for teaching and argumentation, they constitute a second kind of contribution that we intend to explore with teachers participating in our project.

FINAL REMARKS

The modelling approach here suggested has shown to be a feasible way for translating complex contemporary knowledge from the field of cancer research to science education. Efforts intended to bring together knowledge from physics, chemistry and biology can particularly benefit from this approach. While biology can account for knowledge about cell replication and death, chemistry can contribute with information about biochemical processes. In addition to providing knowledge about radiation, physics represents a potential field from which to draw image schemata. Much of our preconceptual bodily function is highly constrained by the nature of the world that we function with. Our basic-level categories are defined by our capacity for bodily movement; also, our image-schematic structures are mainly kinesthetic. Physics is a natural source from which to frame these categories and structures.

In the present work, intestinal epithelium cell radiosensitivity was modeled considering therapeutics as a reference. The historical perspective that recovers the notion of reproductive death helps to make more rich and precise teachers' ideas. Alternatively, truths that make up a valid argument for therapeutics can be reframed to account for carcinogenesis. The models presented here can be enriched in this direction, constituting a fruitful line of investigation. In this attempt, secondary apoptosis would certainly have a place. Observations that apoptosis can occur at long times after irradiation have obvious implications for carcinogenesis, as discussed by Oren (1992). Interestingly, if Johnson and Lakoff are right – as we believe they are, the structure of the inferences would be probably similar.

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Teachers' Ideas about Scientific Models and Modeling

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Abstract

The paper reports a study on teachers' ideas about scientific models. The study was conducted using the same methodology of inquiry adopted for a previous study by Spanish researchers in order to compare results from different cultural contexts. The inquiry has been carried out in different towns in Italy, involving student-teachers with a degree in Mathematics, Physics or Engineering. After a presentation of the results, suggestions for didactical communication are advanced.

Introduction

This study is part of a wider research project involving three countries (Spain, Italy, Mexico) and different samples (prospective/in-service secondary school teachers, humanities university students). The main aim of the endeavour is to compare ideas and conceptions on scientific models held by teachers in different socio-cultural contexts in order to reveal commonalities/differences. In the past four decades research has focused on typologies of or views about scientific models (Black, 1962; Leatherdale, 1974; D'Espagnat, 1983; Gilbert, 1994) resulting in categorizations focused on difference/similarities amongst commonly used scientific models. As a consequence, common characteristics of scientific models are acknowledged instead of a general definition (Hestenes, 1992).

Despite these general views shared by researchers on models in physics, since the early nineties, increasing interest about the role of models and modelling in physics and science education has clearly emerged. Investigations have focused mainly on the functions of 1991; Gilbert, Boulter & Rutherford, models (Gilbert, 1998). students' understanding/conceptions of the nature/role of physics models (Grosslight et al. 1991; Harrison, 2000), models' use in classroom practice (Justi and Gilbert, 2002) and teachers' knowledge/ideas about models and their role/function in teaching (Smit & Finegold, 1995; Van Driel and Verloop, 1999, 2002). In the latter cases, less focus has been dedicated to what teachers think about the nature of scientific models, components and functions as synergically interacting parts of a whole entity. It is therefore meaningful to tackle the issue of how teachers give meaning to the entity of "scientific model", since their ideas may influence classroom role/use of models and modelling activities.

Research questions, sample and inquiry instrument

The main research question addressed is: What are teachers' conceptions about scientific models? As first step, a working definition of scientific model has been adopted as a comparative term for teachers' ideas (Bunge, 1973): "A scientific model is a representation of a real or conjectured system, consisting of a species of objects with its outstanding properties listed, and a set of particular law statements that declare the behaviors of these objects. The essential functions of a scientific model are allowing for making predictions and explanations, and for empirical testing of theories within their scope".

The sample comprised 225 Physics and Math Teachers-To-Be (PMTTB) attending the two-year Post Graduate Specialization School in Secondary Teaching (PGSSST)¹⁷. The data were collected during fall-winter 2005 at the Universities of L'Aquila (AQ, first year), Naples (NA-1, NA-2, respectively first and second year), Rome (RO-1, RO-2, first and second year) and Udine (UD, second year). All those involved had a four or five year university degree, in Math, Physics, or Engineering (Fig. 1a);

¹⁷ In Italy, since 1999, the Post Graduate Specialization School in Secondary Teaching diploma is compulsory to enter the list to be appointed as secondary school teacher.



their curricula included at least two physics courses; physicists and engineers also had one chemistry course; about one third had some previous teaching experience (Fig. 1b).



Fig. 1b. Distribution of the sample with respect to teaching experience and year of PSSGT

We looked for correlations between PMTTB' answers and their: - teaching experience; - course year of specialization school; - university degree. This was done to answer other research questions: Does previous teaching experience influence ideas about scientific models? Are there differences between beginners and sophomore students of the specialization school? Is there any correlation between the university degree type and the conceptions about scientific models?

An additional sample (HUM) of 25 university students attending a history course has been analyzed to investigate a non-scientific group and try to answer research questions such as: How grounded is the idea of scientific model in humanities students? How is it different with respect to that of science graduates?

For the sake of comparison with previous research (Gutierrez & Pintò, 2005), the same inquiry instrument, a questionnaire, has been used that poses three open questions:

- 1) a definition of Scientific model,
- 2) a list of components of a Scientific model
- 3) a list of functions of a Scientific model.

The subjects were also asked to indicate problems in interpreting the questions (if any) and to suggest improvements in their phrasing. The time given was 25 minutes. The analysis has also been carried out in agreement with that research by grouping the answers in literature-based categories: Exemplar (Ex); Procedure (Pr); Scientific Method (Sme); Scientific Model (Smo); Scientific Theory (ST); Teaching method (TM); Not Usable (NU), i.e. answers not belonging to previous categories or impossible to understand/interpret.

Data Analysis

The data have been analyzed along two complementary lines:

- L1 focuses on the 3 inquired features of scientific models (nature, components, functions), looking at the answers as if they were independent data. The reason is that: - each of these features is essential for defining a scientific model; - they have been researched; - knowledge of one/two features does not imply knowledge of the other(s) and may indicate incomplete comprehension of a scientific model. To classify the data better as a fine structure, two sub-categories have been added: p (partial) and meta, to label those answers: - indicating only a subset of the category's characteristics (partial); - referring to properties/attributes of the category (meta). For instance, "a *scientific model is an abstract description of reality*" is labeled Psmo, while "*the model must help in solving difficult problems*" is labeled Metasmo.

- L2 focuses on the individual and his/her coherence level; a global macro-category is assigned according to the three answers. The reason is that the 3 questions required an open answer and inquired into the same theme.

Main Results

Line of analysis 1

Analysis along Line 1 makes it possible to focus on the particular problems of the definition of scientific model. For Question 1 and Question 3 the average frequency of Smo is roughly the same $(46\pm19\%$ and $46\pm14\%$; Question 2 has been perceived as difficult ("*I don't understand what is meant by components*") although the average frequency of Smo is $39\pm12\%$.

Further details about relationships between categories and geographical areas will not be addressed here. In the following, only the distinction between I and II year of PGSSST is kept.

Line of analysis 2

Attention is focused on the correlation amongst the answers. After using the categories of Line 1, it was clear that answers could be grouped in five macro-categories (cf. Table I).

Acronym	Description
Mc1	Model nature, components and functions well understood and phrased
Mc2	Model nature, components and functions partially understood and/or generically phrased
Mc3	Confusion amongst model nature, components and functions
Mc4	Confusion of model with scientific method, theory, teaching method,

Table I: description of macro-categories

Mc5 Poor understanding of model

Answers' distribution is shown in Fig. 2.



About half the sample of the PMTTB (44%) correctly identify nature, components and functions of scientific models, while about 32% show nuances of scientific model interpretation. About 15% show a weak idea of scientific model in at least two answers; in other cases (about 8%) scientific model is confused with scientific method, theory or teaching method. Only 1% of PMTTB did not have a classifiable idea. These results differ from those emerging from the Humanities sample: none shows a clear idea about scientific models and only 35% have a partial understanding about the concept. Another 35% report a non-classifiable idea, while about one third show confusion amongst nature, components and functions of models.

This macro-categorization has been used to look for correlations amongst ideas about scientific models and some of the samples' characteristics (teaching experience, PGSSST year, University degree):

a) for Mc1 category, 25% of PMTTB have no teaching experience, 28% have less than year, 20% have one to three years, 27% have more than three years. A χ^2 test gives a value of 0.8 indicating that the differences due to teaching experience are not statistically significant.

b) the majority (55%) of those who answered correctly attended the PGSSST first year, while the majority of Mc2 macro-category attended the second year. Individuals in Mc3 are equally divided between first and second year, while the majority in Mc4 (57%) attended the first year. The two individuals who fall into Mc5 both attended the first year. The χ^2 test gives a value of 0.2 so once again differences due to year in the PGSSST are not statistically significant.

c) The majority of physicists (56%) and engineers (64%) correctly identify the nature, components and functions of scientific models (Mc1), while this is true for only one third of those with a Math degree. About one fifth of physicists (23%) and of the engineers (19%) belong to Mc2 while about 40% of mathematicians do. Mc3 covers about one fifth of the mathematicians and about one tenth of physicists and engineers (Fig. 3).

Fig. 3. Global answer distribution by degree



A χ^2 test on the distribution of the sample degrees for each macro-category shows statistically significant differences only for Mc1 and Mc2 (respectively p=0.01 and p=0.06). Therefore, it is plausible to think of a possible effect of the disciplinary university education on ideas about scientific models.

Possible implications for research in teacher education

Ideas of scientific knowledge held by teachers-to-be

Results from both lines of analysis support the conclusion that the idea of scientific model is not well grounded in Humanities students, the main difference with PMTTB being a difficulty in understanding the role/nature of scientific models and in recognizing/expressing its main features as well. We only focus here on results from the sample of PMTTB.

Comparison with research carried out with Spanish teachers shows differences that are likely due to the different composition of the sample (Gutierrez & Pintò, 2005): none of the questions has been perceived as more difficult than the others; the category St is the most frequent one; categories such Tm, Ex and Sme have non-negligible frequency.

Referring to research questions outlined in Section 2, we can infer the following trends:

- L1 shows that, overall, scientific models seem to be part of their knowledge, although scant awareness of the important aspects of scientific models emerges from answers to Q2: since, on average, about one sixth were not usable, "components" is probably an unfamiliar term. Moreover, answers focusing on scientific method (about 2%) suggest that the components of scientific models are often disregarded, probably because modelling activities are not yet common at secondary school or university level. Identifying functions of models has been easier, but in some cases only "attributes" of models have been identified and only some functions;

- L2 shows that, globally, more than half the sample know what a scientific model is and the relationships amongst the aspects addressed. In some cases this knowledge is incomplete or only declarative. More than one third of PMTTB show difficulties probably related to "fuzzy boundaries" amongst scientific model aspects, while about one sixth are incoherent and do not recognize at least two aspects of scientific models. Type of university degree seems to be influential on the sample's knowledge about models.

Finally, there has been confirmation of some previous research results: emphasizing only certain functions/characteristics of models, limitedness of ideas about models, no apparent correlation between knowledge of models and teaching experience.

Teacher education

Globally the results from both lines of analysis suggest the following plausible guidelines/criteria for designing/implementing interventions aimed at increasing knowledge of scientific models among pre/in-service teachers:

a) a problem in educational communication about the structure of scientific models emerges from this study: strong focus on the components of scientific models is appropriate. A suitable approach could be to integrate proposals in which the modeling games of physics, i.e. the correspondence between the object/system of the real world and the model, are made explicit (Hestenes, 1992) with activities using modeling environments as Stella, Modellus, etc.;

b) in secondary school and university class practice, scientific subjects are traditionally introduced with strong emphasis on methods for organizing/analyzing phenomena, and less on theories/models. This emphasis on scientific method may plausibly indicate an uncritical attitude (also present in textbooks) towards the belief that methods of scientific investigation differ from those adopted for gaining common knowledge;

c) at the beginning of teacher education interventions, a questionnaire similar to that used here may help focus on the key role played by scientific models and on the hot issue of re-thinking what physics to teach and to whom. Actually, the open answer questionnaire has proved to be a useful tool to investigate the ideas on scientific models held by teachers-to-be, making it possible to elicit facets usually overlooked. Moreover, the proposed categorization may be useful as a grid of analysis for future research, focusing on qualitatively different perceptions about scientific model dimensions.

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Teachers' conceptions of scientific models II: Comparison between two groups with different backgrounds

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Abstract

At ESERA 2005 Conference, we presented the results of a Pilot Study on the topic "*Teachers'* conception of scientific model" (Gutierrez & Pintó, 2005). In this paper, we present a continuation of that work. We have used the same questionnaire, now with a group of experienced teachers. As results, we have found some differences, being the most important: 1) it is possible to analyze the data using fewer categories; 2) the highest concentration of answers belongs to the semantic field of "models"; 3) teachers' answers show more coherency than the first group ones. There still remain some unanswered questions. The same questionnaire have been used in Italy, with several groups of prospective physics teachers (see Danusso et al on this Conference). On the whole, we hope to offer some light on the topic.

Introduction. Antecedents and backgrounds of the work here presented

In the last ESERA Conference (Barcelona 2005) we presented a preliminary study on teachers' conceptions of scientific model (Gutierrez and Pinto 2005). How teachers understand models (Justi and Gilbert 2003) and modeling (Crawford and Cullin 2004) is a point of crucial concern in science education literature. The results of the studies related to this issue show a picture far from satisfactory (Van Driel and Overloop 1999). Some of the difficulties pointed out in the literature address the lack of specific teacher training in the issue of models and modeling (Saari and Viiri 2003), and the necessity of studying what a model is from a theoretical perspective (Gilbert and Buolter 1998). This second aspect drew our attention. A review of literature showed that it is not easy to find a clear definition of what a scientific model is (Wells et al 1995, Gutierrez and Pinto 2004): Scientific model is not usually defined, but instead what you find in papers are lists of characteristics. So, we situated our research question: *How teachers understand scientific models*, in the realm of ontology, in order to avoid multiple descriptions not included in the essential part of a definition.

Methodology

From the work of Bunge (1974-1989) we chose a definition of scientific model based on its ontological characteristics. According to him, the essential characteristics of a scientific model (independent of the field to which the model refers) are as follows:

A scientific model is a representation of a real or conjectured system, consisting in a set of objects with its outstanding properties listed, and a set of law statements that declare the behaviours of these objects.

Being the *essential functions* of a scientific model, according to Bunge, *predictions* and *explanations*. With the above elements we constructed a strategic systemic network resulted in Figure 1 (Gutierrez y Pinto 2005:867), which allows us *to develop a questionnaire* with theoretical grounded categories. The questionnaire was validated by a number of experts in different areas, and by a group of teachers with different subject matter backgrounds.

Sample and findings

We tried the validated questionnaire with a group consisting of 21 Spanish teachers (G1), with different academic backgrounds. Details of the sample and the results of the qualitative analysis of the answers can be examined in Table 1.



As is shown in Table 1, the highest frequency in answers is under the "Scientific Theory" category, followed by (in order of frequencies) "Scientific Model", "Procedure, "Teaching Method", "Exemplar, and "Scientific Method". There were 5 answers "Impossible to classify".

We will say that teachers' answers are *coherent* when the three answers to the questions are classified under the same category. We can identify that this is the case for 9 teachers. This comprises 42,85% of the sample.

The Study with the Second Group

We administered the same questionnaire to teachers of science, to see if there are differences in the results. So, in order to make comparisons possible,

-The research question is now: How teachers of science understand scientific models?

-The *methodology* for carrying out the study was the same as that used with the other group.

-The *sample* consisted of a group of 19 Mexican teachers of science (G2) attending a course of Cognitive Science, who voluntarily completed the questionnaire.

If we compare this sample (G2) with the sample of the first group (G1), two main differences, potentially important for our purposes, can be observed:

-G1 has much less teaching experience than G2.

-In G2 all the members are graduates in sciences; while in G1 there was only one science graduate, and few graduated in science-related subjects: 2 Maths; 3 Business (2 diploma); 1 Computing (diploma).

Findings

Details of the sample and the results of the qualitative analysis of the answers to the questionnaire given by G2 can be examined in Table 2. As with the first group, the categories were inductively established from data.

If we compare the results on Tables 1 and 2, interesting details emerge:

1) Categories "*Procedure*", "*Exemplar*", and "*Teaching Method*" do not appear in Table 2. On the other hand, a new category appears in this Table, "*Help to explain*", which can be defined as shown in Table 3:

San	nple	Classification of teachers' answers to questions 1 (Q1), 2 (Q2), and 3 (Q3) ¹						
Teacher N	Teaching experience	Scientific Theory	Scientific Model	Procedure	Exemplar	Scientific Method	Teaching Method	Impossible to classify
1 Journalism	No exp ⁶						Q1c,Q2c,Q3c	-
2 Law	No exp	Q1c,					Q3	Q2
3 P.Teacher ³	No exp				Q1,Q2,Q3			
4 Business	No exp			Q1, Q2c	Q3c			
5 P. Teacher	No exp	Q2c					Q1c	Q3 No clear ²
6 P. Teacher	2 years				Q3	Q1c,Q2c		
7 Psychology	7 years	Q3c						Q1,Q2 Clear
8 Pedagogy	2 years	Q1c,Q2c,Q3c						
9 Pedagogy	Not stated	Q2c		Q1c,Q3c				
10 Pedagogy	No stated	Q1		Q3		Q2		
11 DD ⁺ in Business	2 years	Q1c,Q2c,Q3c						
12 Business	2 years		Q2	Q1c				Q3 Clear
13 Translation	7 years	Q3c	Q1,Q2					
14 English	Not stated			Q1c,Q2c,Q3				
15 English	15 years						Q1,Q2,Q3	
16 English	6 years	Q1c,Q2c	Q3c					
17 DD Computing	2 years			Q1,Q3				Q2 Clear No answer
18 Environm⁵	1 years		Q1,Q2,Q3					
19 Philosophy	3 years		Q1,Q2,Q3					
20 Maths	No exp		Q1,Q2,Q3					
21 Maths	3 years	Q1c,Q2c,Q3c						

Table 1. Spanish Teachers' sample (G1)

¹ The "c" character added to "Q" on the table means that the answer to that question is only partly in agreement with the definition of the category. ²Clear: easy to understand stated in the questionnaire.
 ³ P. Teacher= Primary teacher; ⁴DD=Degree Diploma (First Cycle University); ⁵Environm= Environmental Sciences; ⁶No exp=No teaching experience.
 -Frequencies: Scientific Theory 17 (10 teachers): Scientific Model 13 (6 teachers); Procedure 11 (6 teachers); Teaching Method: 8 (4 teachers); Exemplar 5 (3 teachers); Teaching Method 3 (2 teachers);

Impossible to classify: 5 (4 teachers); No answer: 1. -Coherent answers: 9 (out 21). 42,85 percentage.

Sar	mple	Classification of teachers' answers to questions 1 (Q1), 2 (Q2), and 3 (Q3) ¹					
Teacher N	Teaching experience	Scientific Theory	Scientific Model	Help to explain	Scientific Method	Others ⁴	Impossible to classify
1 C ³	7 years		Q1,Q2,Q3				
2 B	20 years		Q1c		Q2c	Q3 Technical artefact	
3 B Prim	15 years		Q1,Q3			Q2 No answer	Clear ²
4 P,C	Not stated		Q1,Q3c				Q2 Clear
5 P,C,B	5 years			Q1c,Q2,Q3c			
6 B	10 years					Q1c,Q2c,Q3c graph.schem	
7 P	15 years	Q1,Q2,Q3					
8 P,C	20 years	Q1		Q3c			Q2 Clear
9 G	3 years			Q1c,Q2c,Q3c			
10 B	22 years		Q1c,Q2c,Q3c				
11 B	1 years		Q1c,Q3c				Q2 Clear
12 P,C,M, 2nd	8 years		Q1,Q2c,Q3c				
13 B	25 years	Q1,Q2c,Q3c					
14 P, Q	22 years			Q1,Q2,Q3			
15 P	30 years		Q1,Q3c				Q2 Clear
16 P,C,B	13 years			Q1c,Q2c,Q3c			
17 P	27 years			Q1c,Q2c,Q3c			
18 C	Not stated	Q1c,Q2,Q3c					
19 B	2 years		Q1c	Q3	Q2c		

Table 2. Mexican Teachers' sample (G2)

¹ The "c" character added to "Q" on the table means that the answer to that question is only partly in agreement with the definition of the category. ²Clear: easy to understand stated in the questionnaire. ³ The letters under the number mean that they tasks P. Planta C. Clanta and T. C. Statistical and the statement of th ³ The letters under the number mean that they teach: P=Physic; C=Chemistry; B=Biology; G=Geography; M=Mathematics; 2nd=Secondary (when stated); Prim=Primary (when stated).
 ⁴ Under the heading of "Others" answers given from only one teacher can be found
 -Frequencies: Scientific Model 19 (9 teachers); Help to Explain 17 (7 teachers); Scientific Theory 10 (4

teachers); Scientific Method 2 (2 teachers); Impossible to classify 4 (4 teachers); No answer 1. -Coherent answers: 12 (out of 19). 63,15 percentage.

Table 3. Definition of the new category

Category. Definition	Examples from protocols
HELP TO EXPLAIN: -A representation that is useful for explaining a reality (or activity, or process), or a concept, to others	 Examples: -N14, Q1: "It is a representation of some phenomenon, which serves to scientists for expose its ideas". -N5, Q2c: "Representation of the reality studied (phenomenon) to give other people reasons for events, and how we explain the reality to ourselves".

If analysed more closely, we can observe that

2) In G1, most of the teachers with answers categorized under the categories that do not appeared in Table 2 have no teaching experience (5) or little experience (3 two years experience). Only 1 has fifteen years experience. Three teachers did not refer to the issue.

3) In **G2**, the highest frequency is now under the category of "*Scientific Model*", followed by "*Help to explain*". The category "*Scientific Theory*" appears only in the third place. If compared with **G1** these changes could be significant.

4) On the whole, answers within G2 show *more coherency* than G1: 63.15 and 42.85 percentage, respectively.

5) In G2, the category "Scientific Model" reaches the highest frequency in number of answers and in number of teachers (9; 47.36% of the sample). But the answers are far from precise: Teachers' answers within G2 convey the semantic field of "models"; but they do not refer accurately to "scientific models" in ontological terms. In G1, only 6 teachers gave answers under this category (28.57% of the sample). But, again, the attributed meanings of the answers do not precisely refer to the ontological concept of "scientific model".

In relation to **validity** of the questionnaire, the question Q2 appears four times in **G2** group in the category "*Impossible to classify*", and once as "*no answer*". This could suggest something about the intelligibility of the question, despite the fact that the five teachers explicitly stated that the question Q2 was **clear** to understand.

Discussion

As was said before, the main differences between G1 and G2 samples were: a) teaching experience; and, b) academic background. So, it is necessary to see which of these variables is a better candidate to explain the differences.

We have found some papers that deal with this issue. Thus, Harrison (2001) interviewed 10 experienced science teachers, and he found that physics teachers ranking higher in Grosslight et al levels, followed by biology teachers, being chemistry teachers the lower ranked; Van Driel and Verloop (1999) studied the knowledge of models and modelling in experienced teachers. They reported: *"These results indicate that the chemistry teachers were more strongly committed to logical positivism than the physics teachers, whereas the biology teachers held an intermediate position"*(p 1149). Justi and Gilber (2003) investigating teachers views of the nature of models, report that the educational background of the sample was significant to this respect: *"The FT subsample, four of whom had Primary Teaching Certificates as their major qualification, held the most simple views of the "nature of models"*. (...) *Those with a degree in biology showed a very similar pattern"* (p 1380). *"It was only those with a degree in chemistry or physics who were able to discuss the notion of model in a more comprehensive way"* (p 1381).

Apart from the observed differences, all these three papers agree on the existence of relationships between teachers' academic background and their understanding of models.

The paper presented at this Conference by Danusso et al (2006) is especially significant to our purpose, having the same research question as us, using the same questionnaire to gather data about teachers' understanding of ontological concept of scientific model, the only difference being the statistic treatment of the data, due to the greater number of Italian subjects. The sample they work with is similar to **G1** in teaching experience and similar to **G2** in academic background. Examining the overall results, they show that "Question 2 has been perceived as difficult". (...) "The majority of physicists (56%) and engineers (64%) correctly identify nature, components and functions of scientific models, while this happens only for one third for those having a Math degree".

For all these we are inclined to conclude that the better candidate to give account of the differences found between G1 and G2 is the different academic background between the two samples.

In relation to *the validation* of the questionnaire, we remark that from our results question Q2 seems to present some problem for teachers' understanding. The same is exposed by the Italian team: "Question 2 has been perceived as difficult". This means that the wording of this question needs critical analysis in future uses of the questionnaire.

Future implications

For research

From our data, we can say that one influential factor affecting differences in teachers' understanding the ontological aspects of scientific model is their academic background. Nevertheless, more research needs to be done to see the weight of other factors in these differences, e.g. data from the questionnaire could be enriched with interviews, and shed new light on the issue.

For teacher training

Focusing on ontological aspects presents the advantage of concentrating the understanding of the nature of scientific models on fewer and more essential factors, thus lightening the cognitive load of the concept, and facilitating the introduction of its epistemological characteristics. This could represent a benefit for the development of specific teacher training courses based on this theoretical approach.

This paper represents only a first attempt at the study of scientific model and how teachers understand it from a new theoretical perspective. Much research needs to be done to explore the new possibilities offered by this approach.

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Teacher students and in-service teachers planning and implementing teaching sequences in the school physics laboratory

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Abstract

In this paper we examine teacher students' and in-service teachers' activities while they are planning and implementing experimental teaching sequences in the school laboratory. The participants' questions during the planning phase of the teaching sequences were recorded on audio tape for both mentioned participant groups. Participants' questions revealed four types of boundaries in planning and implementing experimental teaching units. These boundaries are related to physics knowledge, familiarity with equipment and facilities, instructional approaches, and to general organizing of activities.

General background

We have been developing a common framework theory for the physics teacher education at the University of Joensuu in collaboration with the Department of Physics, the Department of Applied Education, and the University Practice School (Nivalainen, Sormunen, Hirvonen 2005;2006). As a result a modified PCK model has been developed. This model arises from the Shulman's (1986, 1987) work and it has been modified on a on a three-year time scale to the format suitable for our use. Our version of PCK is very similar to Marks' (1990) model and includes: 1. Transformed subject-matter knowledge, 2. Knowledge of pupils, 3. Knowledge of instructional strategies, and 4. Knowledge of curriculum and media. In addition, teachers need to master content knowledge and some more general educational knowledge. Furthermore, the special courses for teacher students in the Department of Physics have been examined and slightly modified based on the agreed model.

In the Department of Physics the majority of the special courses for teacher students are included to the Master studies. However, in addition to the traditional physics courses we have two laboratory-oriented physics teacher training courses in Bachelor studies. The first one, the course of *Basic Laboratory Practice for Teachers* concentrates mainly on training traditional school experiments. During the second course, *Laboratory Practice for Teachers in Physics* the students familiarize themselves with computer-based measurement systems and with two instructional approaches, namely modeling (Halloun 2004) and perceptional approach (Hirvonen, Viiri 2002) in addition to traditional laboratory experiments. This paper concentrates on the activities monitored during the latter course.

The course of Laboratory Practice for Teachers in Physics was introduced first time in 1994 and modified in 1997 when the first steps applying the instructional approaches as a theoretical framework for laboratory activities were taken. In practice, the ideology of the perceptional approach was lectured and some ideas were required to be applied to the laboratory activities. The development work moved to a new level in the 2005 when some ideas of modeling were included to the National School Curriculum. So modeling as an instructional approach was taken on the course program in the 2005. The implicit aims of the course are related to the first and the third elements of the PCK.

During the course the students plan and fulfill experimental teaching sequences in the groups of two or three persons in the context of the presented instructional approaches. Other students act as high school students participating to the lessons. The course is supposed to be taken on third year of the studies after completing the traditional physics courses. Another subject group, 13 in-service teachers participated only on the course of *Laboratory Practice for Teachers in Physics*. In addition, they had a whole course, 32 hours lectures, concerning instructional approaches before the laboratory course. The in-service teacher course was held on weekends because of their daily work. Within a few weekends the inservice teachers planned and implemented teaching sequences in two cycles like the teacher students did on their program described below.

The teacher students took both of the laboratory courses but didn't have a separate course for instructional approaches. They had four hour lessons during the first week about the basic ideas of the instructional approaches before getting to the laboratory. The course schedule for teacher students is presented in table 1.

Table 1. The course schedule for teacher students					
Week 1	Lectures on Instructional Approaches				
Week 2	Visiting the laboratory and theoretical examining of the first teaching unit (homework)				
Weeks 3-4	Planning phase (9h in laboratory)				
Week 5	Presentation phase (1h per teaching unit, 8h to be participated)				
Week 6	Writing a report on first teaching unit and theoretical examining of the second unit (homework)				
Weeks 7-8	Planning phase (9h in laboratory)				
Week 9	Presentation phase (1h per teaching unit, 8h to be participated)				
Week 10	Writing a report on second teaching unit (homework)				

On the week 2 the teacher students visited the laboratory and were familiarized shortly with the facilities and a computer-based measurement system. They were also given the topics to be planned for the teaching sequences with two different upper-secondary school text books in which the instructional approaches discussed are used. The laboratory part of the course had two cycles which took one month time each. During first two weeks (Weeks 3-4) in laboratory they had total nine hours time to plan their one hour presentation. On the first laboratory session they were also required to present a concept map and some plans about their topic to the tutor. This was done in order to see that groups had studied the physics structure of the topic before going to the laboratory. After two weeks of planning and testing, the teaching sequences were implemented. The sixth week was reserved for writing a report and for studying the physics structure of next topic. The second round of planning and implementing physics lessons was held during next four weeks.

Methods

This study was held in order to find out what kind of difficulties the teacher students and inservice teachers would confront while planning and implementing laboratory-oriented physics teaching sequences. The research strategy could be described as explorative case study (Stake 1995) since at the beginning of the course we didn't have clear expectations what kind of boundaries the examined groups had in performing but we wanted to see if some general trends arises from the recorded material.

The planning phases were recorded on audio tape, 30h for the teacher students and 21h for the in-service teachers, in order to find out what kind of questions the participants would ask the tutors during the planning process. The teaching sequences were videotaped and stored with the reports of implemented teaching sequences for later use. The teacher students were also asked to respond to some written questions in order to get more information about encountered boundaries while planning and implementing experimental teaching.

The audio tapes were listened and all of the participants' questions, comments and explanations concerning the performing in laboratory were written down. The first author classified these notes, after which another researcher classified the notes by using the created categories. After individual classifying the non-overlapping items were discussed and set to suitable categories in consensus between the classifiers.

Results

The found categories are presented as diagrams for both groups. Figure 2 represent the boundaries on a laboratory-oriented course for the teacher students and the in-service teachers. The overall number of reported questions, comments and explanations concerning these problems were roughly the same for both of the groups.



The first domain is related to the physics knowledge of the topic to be planned. Both of the groups ran into questions during the planning stage if they were not comfortable with the structure of the physics related to the phenomena or if the needed concepts were not clear for them.

The second limitation is the ability to apply instructional approaches into practice. The difficulties on using instructional approaches can be noted also from the difficulties in planning and implementing experimental instructional units which clearly aims to teach given idea or area of physics.

The third boundary in planning teaching sequences is the familiarity with the laboratory itself. The participants do not always know what kind of equipment or computer programs is available in the laboratory or how these equipments or programs work. Also, they are not sure if they should use traditional meters or computer based measurement systems in order to find the best way to make measurements and data processing.

The last limiting factor is an ability to organize activities of the student group during teaching sequence.

Discussion

We generalize that teacher students' and in-service teachers' skills and knowledge can be classified into four different categories which define their possibilities to realize the given experimental teaching task. First of all, one has to note that the diagrams represent only the proportional distributions of the found boundaries and do not describe at all about the type of presented questions.

In-service teachers had generally less questions and comments on understanding physics knowledge than the teacher students had. Teacher students have had their traditional physics courses just before the lab courses but they haven't had any opportunities to test their

knowledge in practice anywhere. Consequently, the in-service teachers have seen physics theories working in practice in school experiments so the result sounds credible.

The planned teaching sequences consisted of a fragmented set of experiments many times and didn't have clear shared aim, even if some very positive exceptions appeared especially among experienced teachers. Generally, the participants on both of the groups didn't ask much help about the usage of the instructional approaches in order to build their presentations better even they were required to use them. This implies also problems in understanding the significance of instructional approaches even if the participants they were familiarized with the instructional approaches.

The participants didn't always understand the focal point of physics teaching - what should be taught at school. Instead, they spent time in searching nice-looking equipment and thinking what could be taught with them. One could assume that the in-service teachers should be more familiar with the laboratory and its possibilities than the teacher students. However, they had more questions in using different equipment than the teacher students. Some comments imply that in-service teachers had questions because the facilities of the used laboratory were not identical to their own.

In-service teachers don't have as much problems in organizing groups and equipment as teacher students. By working at schools they do it all the time, so the result is not surprising. Obviously, the inexperienced teacher students have problems on organizing groups and equipment.

In addition, a more profound analysis of the presented questions reveals that the significance of different boundaries seems to vary depending on the physics topic. Consequently, it even seems that different topics of physics should be treated differently, especially considering the features of the applied instructional approach. This result will guide the implementations of the forthcoming courses.

Based on the results of this study, it strongly seems that both groups, teacher students and inservice teachers need more concrete guidance during this kind of course, especially in utilizing different instructional ideas in planning processes. The lectured information is not enough for effective working. In addition, the given physics topics should probably be divided into smaller parts, because at the moment the participants use lot of time defining the extent and content of the experimental teaching task. These revisions might help participants to improve the quality of their experimental teaching units and create more space between the four limiting domains.

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Examination of Pre-service Physics Teachers' Knowledge of Models and Perceptions of Modelling

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Abstract

Pre-service science teachers' knowledge of models and modelling is crucial because it may influence the way they implement modelling in their classrooms. Therefore, providing opportunities for teacher candidates to improve their knowledge of models and skills in odelling should be the subject of pre-service education. The purpose of this study was to examine the effects of model-based teaching on the pre-service physics teachers' knowledge and perceptions of models and modelling. Results indicated that implementation of modelbased teaching in the pre-service teacher education program did not make too much influence on the pre-service physics teachers' general knowledge of models. However, detailed examination showed that the type of the model constructed or used in model-based teaching generated some differences between the knowledge of pre-service teachers in the experimental group and the knowledge of pre-service teachers in the control group in terms of characteristics, roles and functions of models. Moreover, promoting model-based teaching in the pre-service teacher education program might affect the pre-service physics teachers' perceptions of modelling positively and lead them to use models in their teaching. These conclusions have implications for teacher education.

Introduction

Models play a central role in physics education. To introduce modelling successfully in teaching physics requires that teachers have an appropriate understanding of models and modelling.

Science Teachers' Knowledge and Views of Models and Modelling

According to Boulter and Gilbert (2000), the modelling and models are important for three major reasons: "first, modelling and models are explicitly recognized in science and science education; second, they play a major role in the nature of science and its achievements; and third, they play a major role in technology" (p. 344). Harrison and Treagust (2000) recommend that when analogical models (physical objects, pictures, equations and graphs) are presented in a systematic way and capable students are given ample opportunity to explore model meaning and use, their understanding of abstract concepts can be enhanced. In order to help students in learning science, Justi and Gilbert (2002b) advocate that teachers should have comprehensive understanding of the nature of a model in general, and know when, how and why the general idea of models and specific or historical models should be introduced in their classes.

Therefore, researchers have developed interest in teachers' knowledge of models and modelling. Van Driel and Verloop (1999) conducted a research in the Netherlands to map the experienced science teachers' practical knowledge with respect to models and modelling in science, in terms of the common characteristics of models, the roles, and the functions of models in science. Their results showed that "the participants shared the same general definition of models; however, their content knowledge of models and modelling proved to be limited and diverse" (p. 1141). Van Driel and Verloop (2002) also aimed to find teachers' knowledge of teaching and learning of models and modelling in science education. Seventy-four science teachers in the Netherlands completed the questionnaire. The results of their study indicated that "teachers differed in the extent to which they use teaching activities focusing on models and modelling in science, and their knowledge of students' conceptions and abilities in this domain was either limited or not very well integrated with their knowledge of teaching activities" (p. 1270).

Justi and Gilbert (2002b) interviewed 39 Brazilian science teachers to ascertain their perceptions of the role of models in science teaching. The teachers presented an awareness of the value of models in the learning of science but not of their value in learning about science. In the same research, Justi and Gilbert (2002a) also analyzed the questions around the theme "What are the knowledge and skills that a person should have in order to produce a scientific model successfully?". Their results illustrated that "interviewees were not aware of the 'model of modelling' framework, and they seemed to be thinking of modelling as something done primarily by scientists, or by other people who were less effective at this than scientists" (p.375). Harrison (2001) interviewed 10 experienced

science teachers about their understanding of the analogical models that they used to explain science to their students. Unlike other results, he found that these 10 teachers had rich, comprehensive and creative view of modelling.

Based on their findings, Summers and Mant (1995) suggest that essential prerequisites for primary teachers if they are to teach astronomy are: knowledge of accurate, scientific, structural models and being able to use these models to explain and predict simple phenomena.

Reviewing of the literature indicates that teachers may have general idea of models but their knowledge of using models in teaching and learning science is limited.

The Purpose of the Study

Pre-service science teachers' knowledge of models and modelling is crucial because it may influence the way they implement modelling in their classrooms. Therefore, providing opportunities for teacher candidates to improve their knowledge of models and skills in modelling should be the subject of preservice education.

The purpose of this study was to examine the effects of model-based teaching on the preservice physics teachers' knowledge and perceptions of models and modelling.

Methodology

Experimental design was used for the study. Model-based teaching was implemented in the experimental group.

Participants

Participants of this research were 35 pre-service physics teachers taking the method course. The method course is one of the courses in science teacher education program. While there were 16 pre-service physics teachers in the control group, the population of the experimental group was 19. The participants were randomly assigned to the groups.

Model-Based Teaching Context

Boulter, Buckley and Walkington (2001) reveal that a model-building sequence begins with students expressing initial models. Then, students face challenges to their existing models in the field along with the need to negotiate new group models, and finally, they report models in their presentations and endure more challenges (Boulter et al., 2001) This sequence was provided in modelling context of this study by assigning a Moon project to the experimental group including observation, sharing the findings, expression of the ideas, and construction of a model. In other words, the pre-service teachers in the experimental group had to construct their own models and use them to explain some lunar phenomena in the context of model-based teaching.

Instruments and Data Collection

The Likert-type questionnaire consisting of 57 items was administered to both control and experimental groups at the end of the course. This questionnaire was developed by Justi and Gilbert (2003) to identify teachers' content knowledge about models and modelling.

The precise wording used in the questionnaire may influence respondents so that they may agree with a given idea. Therefore, one open-ended question was asked to the pre-service teachers in the experimental group to determine their ideas about modelling. The question was: "How do you perceive modelling with regards to teaching and student learning?"

Data Analysis

Descriptive statistics were used for data analysis. Mean response was based on a three-point Likert scale, with 0 ="I don't agree", 1 ="I partially agree" and 2 ="I agree". If the pre-service teacher was not sure, it was requested from her/him to circle the question mark. Factor analysis was conducted to confirm that the questionnaire measured pre-service teachers' knowledge of models and modelling. The reliability estimate for the questionnaire was calculated by using the Cronbach's alpha formula. Independent t-test analysis was performed to examine the difference between two groups.

Qualitative analysis involved verbatim transcripts of the written responses. The transcripts were analyzed inductively to identify themes that described the pre-service physics teachers' perceptions of modelling.

Results and Discussion

The questionnaire was subjected to principal component analysis by using Varimax rotation. The explanatory factor analysis generated 20 factors with an Eigen value of one or greater than one, which explained the 89 % of the total variance in the data. Cronbach's alpha reliability for two groups was

Items	Group	Ν	Mean
*A model can represent an object	Control	16	1.12
	Experimental	18	1.61
A model can represent an idea or ideas	Control	15	1.26
	Experimental	17	0.94
A model is used as a reference or standard to the followed	Control	14	1.21
	Experimental	17	0.94
A model is used to visualize something that is abstract	Control	16	1.56
	Experimental	19	1.16
A model is used to explain something	Control	16	1.37
	Experimental	19	1.68
A model can exist because an individual person wants it	Control	15	1.00
	Experimental	19	1.37
*A model can exist because a group in society wants it	Control	14	1.00
	Experimental	18	1.50
A model can exist because scientists want it	Control	16	1.06
	Experimental	19	1.42
A model is useful when it is as close to what is being represented	Control	16	0.75
as possible	Experimental	19	0.42
A model is useful when it does not need an excessive amount of	Control	14	0.78
prior knowledge	Experimental	18	0.44
A model is useful when it can be handled	Control	16	1.06
	Experimental	19	1.37
A model can be represented as a graph	Control	13	1.23
	Experimental	19	0.89
A model can be represented as a diagram	Control	14	1.50
	Experimental	15	1.06
The production of a model is a process that depends on its aims	Control	16	1.50
-	Experimental	19	1.73

Table 1. Mean values for some of the items in the questionnaire

* significant at p≤0.05

found as .70. Cronbach's alpha value for the control group was .81 whereas this value was .58 for the experimental group. These results illustrated that the questionnaire had internal consistency.

The independent t-test analysis of the data showed that there was not much difference between the knowledge of the pre-service teachers in the control group (mean = 1.28) and the knowledge of their peers in the experimental group (mean = 1.31) (t = 2.578, df = 33, p = 0.025, one-tailed). The pre-service physics teachers in both groups had moderate content knowledge of models and modelling.

The analysis of means showed some differences in the pre-service physics teachers' knowledge about some of the items. The items whose mean difference was equal to .02 or greater than .02 were given in Table 1. According to Table 1, the pre-service physics teachers in the experimental group had better understanding of the following items: a model can represent an object and exist because an individual person, a group or a scientist wants it; a model is used to explain something and the production of a model is a process that depends on its aims. From their point of view, a model is useful when it can be handled. On the other hand, the pre-service teachers' in the control group had better understanding of the following items: a model can represented as a graph and a diagram; a model is used as a reference to the followed and to visualise something abstract. As far as they are concern, a model is useful when it is as close to what is being represented as possible and when it does not need an excessive amount of prior knowledge.

The type of the model constructed or used in model-based teaching might cause the difference in these items. Because the pre-service teachers in the experimental group were required to construct a concrete model to show and explain their understanding of some lunar phenomena, they might have come up with the ideas that a model could represent an object and be useful when it can be handled.

The results gathered by analyzing the open-ended question are presented as vignettes and extracts to explain how the pre-service physics teachers perceived modelling.

P1: It is easy to explain an event on a model. I am definitely going to use this technique in my practice.

P2: Construction of a model is a very effective way to provide thinking. It can resolve many problems in the instruction because students can find the solution by seeing and doing. Many difficult things can be explained by using a model.

P3: Construction and use of a model have positive effects on conceptual learning because they provide an opportunity to turn abstract events into concrete. But construction of a model is difficult and the model may not provide all the answers.

P4: Construction and use of a model helped me to look at the universe with different perspectives. I tried to construct a logical but not costly model.....Use of modelling in teaching has advantages because it provides meaningful learning, draws attention, motivates students, prevents recitation and helps teachers to teach. However, if a model does not represent the phenomena exactly, it may cause misconceptions.

P5: I developed hypotheses during the Moon observations and I tested them on our model. Models make abstract events concrete and provide easy explanations. Construction and use of models facilitate meaningful learning and develop students' psychomotor skills.

P6: I have learned many new things. Textbooks are not the only source of knowledge. Students can achieve the knowledge by constructing models.

P7: Modelling helps us to understand the events that are difficult to visualize in the mind. It also helps to keep the information in the long-term memory. In addition, modelling is a good teaching strategy that can take students' attention and increase their interest.

P8: Construction and use of models have benefits of explaining concepts and events visually. I tested my hypotheses that I had developed during my observations on the model.

P 9: Modelling helps us to understand the events like the solar system that we cannot examine directly. Visualization of these events can enhance the retention of learning.

P10: Construction of a model requires group working. I really had fun when we were working on our model. Working on the model helped me to understand some lunar phenomena better. Furthermore, modelling is a very effective strategy to motivate students.

P11: Models help us to explain the events that are difficult to explain. Modelling has increased our interest. As students, we are happy to create something. My motivation has increased, too. I could not construct in my mind that why we always see the same face of the Moon. I have learned it very well because of modelling.

P12: As a group, we did brainstorming about how we were going to design and construct our model. We tried to construct our model as similar as possible to the real situation. The constructed model may not explain all the reality. The more the model represents the reality the more it facilitates learning. We need to emphasize the difference between the model and the reality as we did during our presentation, otherwise modelling may cause misconceptions. To see the lunar eclipse, the phases of the Moon and the relationship between the orbits on the model were very helpful for me.

Results indicated that the pre-service teachers in the experimental group conceived of modelling as an effective teaching strategy. They believed that use of models in teaching would make their practice easier since models could provide visualization for some events that were difficult to explain. Regarding student learning, the pre-service physics teachers thought that modelling might be very helpful because it could increase student's motivation and facilitate learning. Furthermore, the pre-service physics teachers were aware that use of models had limitations and if these limitations were not elicited during teaching, they might create misconceptions for students. They also believed that a model had to be close to the real situation it represented.

Conclusions and Implications of the Study

The following conclusions can be drawn from the study. Implementation of model-based teaching in the pre-service teacher education program did not make too much influence on the pre-service physics teachers' general knowledge of models. However, detailed examination showed that the type of the model constructed or used in model-based teaching generated some differences between the knowledge of pre-service teachers in the experimental group and the knowledge of pre-service teachers in the control group in terms of characteristics, roles and functions of models. Moreover, promoting model-based teaching in the pre-service teacher education program might affect the pre-service physics teachers' perceptions of modelling positively and lead them to use models in their teaching. These conclusions have implications for teacher education.

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Laboratory Teaching with Measurements, Data Analysis and Modelling: An Introductory Course for Future Physics Teachers

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Abstract

Over the last years there has been an increasing interest in investigating teachers' understandings about the central role of models play in physics education and their intentions related to implementing such modules in their teaching. In this work we present the design of the course, offered to prospective Physics teachers, introducing physics students-teachers to ways of incorporating and integrating modern ICT tools (measurement and data collection, advanced data analysis and modelling techniques) in the teaching of Physics. Results on the on the application of the course to final semester physics students are presented and discussed.

Introduction

Over the last years there has been an increasing interest in investigating teachers' understandings about the central role of models in physics education and their intentions related to implementing such modules in their teaching (VanDriel & Verloop, 1999; VanDriel & Verloop, 2002; Justi & Gilbert, 2002; Redfors et al, 2003; Sperandeo-Mineo et al, 2003; Crawford, 2004). Many studies have demonstrated the importance of the education of prospective physics teachers by involving them in such activities, thus improving their beliefs and practices on using models in their teaching (Hestenes, 1996; Justi & Gilbert, 2002; Wells et al, 1995).

In the light of this, a laboratory course was designed in the Department of Physics, AUTH, introducing students to ways of incorporating and integrating modern ICT tools in the teaching of Physics. Student teachers were systematically introduced to the implementation of MBL and video-measurement (VBL) techniques for data collection, to advanced data analysis and to numerical modelling procedures for the description, elaboration and explanation of their experimental data and then assigned to design, carry out and present a complete study of selected phenomena of Introductory Physics, applying those tools and techniques, going from data measurements through data analysis to the creation of the model that describes the phenomenon and its correlation with experimental data. They were all asked to work with phenomena they already knew well, trying to elaborate ways of better explaining them and presenting them to a classroom.

As one could argue that "data analysis" can be considered as "modelling", we should differentiate at this point the context given to those terms in this study. With the term "data analysis" we refer to the process of systematically applying mathematical tools (tables, charts, graphs) and functions (curve fitting, curve matching) for organizing and examining the collected data (Rogers, 2001). While on the other hand, with the term "modelling" we refer to the process of creating a model that describes, explains and predicts the real phenomenon under consideration, representing its behavior and accounting for all its properties and interactions with the environment (Schecker, 1998; Treagust et al, 2002; Etkina et al, 2006). For the creation of such a model student use fundamental concepts and laws of physics characterized with quantitative relationships whose parameters are measured (experimentally determined).

A number of publications have suggested the effectiveness of independent use of MBL measurements (Thornton, 1999), VBL (Beichner, 1996; 1999), data analysis (Ryder & Leach, 2000; Rogers, 2001;) and modelling (Wells et al, 1995; Hestenes, 1996; Justi & Gilbert, 2002; Redfors et al, 2003; Crawford, 2004) and have brought out students' and teachers' ideas on those procedures during teaching (VanDriel & Verloop, 1999; 2002; Justi & Gilbert, 2002; Sperandeo-Mineo et al, 2003). Recent works have shown the added value of the combined use of measurements and modelling in teaching (Schecker, 1998). In our work we extend the measurement – modelling scheme, introducing data analysis as intermediate step.

The scope of our work was to investigate if student teachers can

- accomplish integrated laboratory tasks that combine experimentation, data analysis and modeling,
- build models, correlate theoretical with experimental data and refine the initially proposed model
- discriminate data analysis from numerical modeling

Regarding the two different measuring techniques used in this work (MBL - VBL), we wanted to find out which amongst them is:

- more appropriate for introduction to modeling
- more efficient in gaining deeper understanding on the phenomena

In this paper, the design of the integrated laboratory-teaching course and its application to physics student teachers are presented and the results of its implementation by prospective physics teachers are discussed.

Description of the course

The course was addressed to final semester physics students, prospective Physics teachers (N=24) who were familiar with computers but has no prior experience in the design and application of ICT in teaching. It lasted for a period of twelve weeks, with 3 hours long weekly sessions and was divided in 2 parts: theoretical and integrated laboratory activities, of six weeks each. Both sessions are described further below (fig. 1).

During the first six weeks students followed a series of theoretical sessions that introduced them to the modern ICT tools and techniques and to ways of their proper use and their implementation in physics teaching. Theoretical sessions were also divided in two subparts. The focus during the first subpart (4 weeks) was to give the basic framework and accompanying tools for:

- MBL data logging
- VBL measurements
- advanced Data Analysis
- numerical modelling



In the second sub-part of the theoretical sessions (2 weeks) students were given detailed working examples and were introduced in details to the use of the integrated environment Coach 5. The specific software was chosen because it is simple and user friendly and allows the combination of data logging or video measurements with data analysis and mathematical modelling in real experimental conditions (Rogers, 2003).

The second half (lab work) of the course, of a total duration of six weeks, was divided in three phases, namely: "pre-lab" (1 week), "in-lab" (4 weeks) and "post-lab" (1 week). During the "pre-lab" phase students formed teams of two and were asked to choose a project from a number of proposed projects that could be addressed either with MBL or VBL techniques for measuring. The projects covered the areas of mechanics, thermal phenomena and electricity (for MBL) and kinematics (for both MBL and VBL). Courseware material was also prepared

and distributed to the teams during this phase, made available to them both in a cd and through the course's webpage.

During the "in-lab" phase each team had a hands-on tutorial on Coach 5 (1 week). Then working alone (3 weeks) they had to:

- set up a data logging experiment from scratch or find the appropriate video (VBL) from a collection of 150 available videos (Pasco Scientific series)
- prepare the electronic activity that would allow them to collect experimental data (measurements)
- analyze the collected data (curve fitting).
- build their own model to describe the phenomenon.
- refine their model in order to match experimental data

At the "post-lab" phase, students were asked to propose ways to incorporate this procedure to the classroom teaching {learning type 2 according to Stratford (Stratford, 1996)}, to summarize their work in a typical lab report and to present it in class (HTML or PPT presentation).

Courseware material included:

- a basic theoretical background on the uses of ICT in education
- worksheets for the lab work and templates to prepare the electronic activities
- a quick guide to the use of Coach 5 (in Greek)
- a collection of selected papers on the effective use of ICT in teaching



Course application

Each team was scheduled to work in-lab for four, 4-hours long, laboratory sessions in the Education Technology Laboratory of the Department. At the beginning of their first session the teams worked with a laboratory assistant (one of the authors) who gave them a very detailed hands-on tutorial on the use of software and hardware. After the first tutorial session students worked alone but the assistant was present during most part of their in-lab work, discussed with them and helped them with any issues raised regarding the physics of the subject, the experimental set-up and so on. All sessions were recorded.

Our research data was collected by voice recording all in-lab sessions and taking notes on spot. Additional sources of research data consisted the written reports of the teams and the final oral presentations.

Results and discussion

Student teachers had the basic theoretical knowledge as expected for final semester students. Regarding their work during the "pre-lab" phase, they studied the courseware material and prepared a draft design of their MBL experiment or decided which video was most appropriate for the VBL activities.



During the "in-lab" phase, both the MBL and VBL teams completed the first part of their experimental tasks (i.e. measurement and data analysis-curve fitting) without facing of any problem (fig.3). Students were easily passed from mathematics to physics, assigning variables to fitted parameters, which is more-or-less expected from Physics students in their final year of studies. In reference to modeling tasks, students in their first approach, were mostly trying out, a "final equation" model instead of "first-principle" calculation. For example, they were mostly thinking in terms of the equation of the form $s = s_0 + v \cdot t + \frac{1}{2}\gamma \cdot t^2$ for accelerated motion, instead of first principle evaluation of velocity as due to acceleration, change in distance as due to velocity, etc. It took them long discussion with the laboratory assistant and few unsuccessful trials to realize that "first-principle" modelling does not mean function fitting but forming and solving a set of fundamental equations to predict and describe the behavior of a system (Jackson, 1996; Schecker, 1998).



In their modelling attempts, all the VBL-teams executed their model-tryouts without any apparent difficulties; model-calculated curves were almost overlapping with experimental data (fig. 4). That was not the case for the MBL-teams; when students built "first-principle" models and tried to compare experimental data to calculated results; they observed bigger or smaller discrepancies between the experimental and theoretical graphs (fig. 5), originating by side effects (e.g. heat-losses, friction, etc.) either due to a non-carefully conducted experiment or unaccounted in building of models

On-spot observations show that the "problem" of data-to-model discrepancy, became a useful boost that guided MBL-teams to a deeper understanding of modelling (model limitations) and also on factors for a better experiment design. In fact, all MBL-teams, asked to re-design and re-execute their experiment for "better results" (as they quoted). The difference on the impact of modelling in MBL and VBL teams is depicted in figure 6.

Fig. 5: Modelling Thermal equilibrium MBL – activity. The model (a) and the graphs from initial (b) and redesigned (c) experiment



Analysis of the data gathered by final written reports and oral presentations gave us evidence that VBL-activities are suitable for introducing students to modelling, as video-taped experiments are usually carefully designed and thus, leaving students to concentrate on the modelling process. MBL-activities on the other hand, may be considered superior to VBL as they give students the possibility to think over phenomena and redesign their experiment



Concluding remarks

This work demonstrates the effectiveness of data analysis measurements and modelling steps. Students can accomplish satisfactory and in time integrated laboratory assignments combining experiments, data analysis and modelling. Student teachers can build their own models, correlate theoretically calculated data to the experimental ones and then refine the initially proposed model to better match the experimental results.

Regarding the two different measuring techniques used in this work (MBL – VBL), VBLactivities appear more appropriate for introduction to modelling while MBL-activities may prove more efficient in gaining deeper understanding, realize that real phenomena are not ideal as in textbooks and consider the side-interactions involved. It seems that discrepancies between model calculations and experimental data, occurring more often in MBL than VBL experiments, may prove valuable in helping students reflect upon modeling a way or a means to represent the behavior of the system (Jackson, 1996), through a set of first principle equations, or of the limitations of the model itself.

Based on the evaluation of recorded discussions and final written reports of the teams we notice that when upon completion of the extended measurement–data analysis–modelling scheme students arrive to better discriminate among the two processes; data analysis and numerical modelling.

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Motivational Strategies

The Systematic Approach to a Biomedical Physics Course: a Case Study at Vilnius University

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Abstract

The demand of physics knowledge is essential due to the rapid development of different sciences and new technologies in the 21st century. Physics is a significant subject in different programs of study. However, physics is often excluded from study programs or is detached from the real life context, society and the environment. Moreover, students try to avoid learning physics, if it is not a formal prerequisite for a study program or if it is not clearly applicable for their future activity. This problem is especially evident in teaching students for other specialties (medicine, e.g.) and calls for new strategies in physics teaching and learning.

VU has implemented a pilot project "Medphystrain" supported by the EU Leonardo da Vinci programme and is carrying out a new project "Dicort". These projects are aimed at improving the quality of Biomedical Physics instruction for all-level medical students. A Systematic Approach (SA) to this course was developed and implemented. The SA builds upon the results of the first project and seeks to ensure the efficiency of students' learning, based on the principles of learning, flexibility, socialization, individualization and integration for the educational environment. Newly redesigned programs and the SA were tested for different medical study programs.

We will present the activities and outcomes of the projects and new programs. The results of empirical research about SA influence upon students' attitudes towards teaching, learning and physics will also be put forward.

Introduction and problem definition

The knowledge of physics has touched and enriched all the sciences in the 20th century and has extended its influence to the technological and economic development of societies in this century. This demand for physics knowledge has been growing in parallel with the influence of physics upon different study programs at universities. At the same time, the community of physicists has identified many problems in physics education. Different authors and organizations in their research write about students' negative attitude in physics courses, the decline of student motivation and other problems as well [1, 2, 3 and others].

Lithuania has been experiencing a similar situation [4, 5]. Many physics courses are very often detached from everyday reality, ecological problems, and societal needs. A few years ago, the objectives and contents of physics courses and also teaching methods were the same for different study programs. Students could often not understand why they had to learn about a particular physics phenomenon which they did not see as being linked in any way with their study program and their future professional activities. This problem was especially evident when teaching students at the Vilnius University (VU) Faculty of Medicine.

Furthermore, for the last two decades VU has been experiencing an obvious decrease in physics lecturing time allocated to medical study programs. As is illustrated in Fig. 1, the most recent allocation for physics is only 48 hours.



The situation at VU compares unfavorably with most other European countries and with the Kaunas University of Medicine (KMU) where an average of 90 hours is allocated for physics in the medical study program. The amount of teaching time devoted to physics in Scandinavian countries is similar to that at VU, but in those countries problem-based

learning is applied in the education of medicine specialists. Problem-based learning integrates different subjects, therefore in reality more teaching time is devoted to physics [6].

Meanwhile, science education in general play an important role in educating scientifically and technologically informed medical professionals, because new discoveries in biomedical diagnostics and treatment lie at the interface of multiple disciplines including physics, chemistry, biology and computational science. During the last few decades, in many countries changes in interdisciplinary cooperation in the field of undergraduate medical education have been rapid and sometimes radical, whereas in Lithuania the old habits remained practically unchanged. This situation has called for new strategies in physics teaching and learning.

Projects and new strategy in biomedical physics

Together with the Vilnius College Health Care Faculty and with partners from Germany, Poland and Latvia VU implemented the pilot project "Medphystrain" supported by the EU Leonardo da Vinci programme in 2000-2002. The aim of this project was to improve the quality of Biomedical Physics instruction for three levels of medical students (college, university students and medical professionals):

• to reorganise training in biomedical physics course,

• to develop newly redesigned, harmonised programs of Biomedical physics for three level trainees,

• to create new products (handbooks, illustrative materials, new equipment and materials for traditional and virtual experiments) for teaching and learning.

Complete information about the project and its results can be found at the webpage: <u>http://www.ff.vu.lt/leonardo</u>.

These institutions, together with partners, are now carrying out a new project "Dicort" (http://leonardo.spf.viko.lt). The goal of this project is to create an e-learning resource (the Digital Compendium) for nursing education with the aim of raising the quality of student learning, enhancing motivation and providing learning with possibilities for self-assessment and feed-back. This will be a new form of teaching and learning for vocational training practises in Lithuania and will enrich the teaching basis of Lithuanian colleges because there is a lack of special ICT tools for high quality learning and teaching. Fostering collaboration and seeking to enhance and optimize Project outcomes the creators of the DC will integrate the curriculum experiences of their European partners (from Belgium, Denmark, Latvia and Norway) and exchange information, taking into account new pedagogical approaches and new forms of cooperation among learners and teachers.

The Systematic Approach to Physics Study Process (SA) was developed and implemented upon the results of the first project on the Biomedical Physics course at the VU Faculty of Medicine. The SA sought to ensure the efficiency of student learning, based on the principles of flexibility, learning, socialization, individualization and integration for educational environment [7, 8]. SA is a new teaching/learning model, which emphasizes the openness and flexibility of the educational environment, and is used to foster the transition from a passive to an active, from a teacher-centered to a student-centered educational learning

environment and is directed towards students who study physics not as their major at the University (e.g. medicine).

The main steps of SA:

1. The integration of study program aims, student competencies to be gained and goals of physics module and subsequently building the physics module content.

2. The assessment of student's experiential knowledge of physics acquired at school and in life environments and the identification of the student's approach to physics, teaching/learning methods and his/her learning competence.

3. The discussion of the conditions of learning goals for individual students in the context of a study program and physics course. Such discussions about individual learning objectives are the key point for student motivation in the study process: a student can understand that knowledge depends on his/her experience and activity; this makes him/her feel equal in decision making, stimulates self-confidence and motivates a deep attitude to learning.

4. The construction of the content of an individual student's module. This module is constructed in the context of the content of the basic physics course and the learner's real potential (specifics of a chosen study program, student's experiential knowledge, and his/her learning competence).

5. The selection and implementation of study tactics (methods, ways and tools of teaching and learning, feedback) in the educational environment in order to most effectively reflect each student's experiential knowledge in physics, his/her learning experience and style.

6. The evaluation of physics knowledge and acquired competencies.

Research methods

The effectiveness of this theoretical model and its influence upon students was tested in Medicine, Odontology and Public Health study programs at VU during the last two years. Two hundred and twenty university freshmen (100 students in 2004/05 school year and another 110 students in 2005/06) and 10 physics teachers participated in this study. The essence of the educational impact was the SA.

As part of the large case study, students were surveyed twice during their physics course (before and after the educational impact). For the present study we examined measures specifically related to the students' attitudes to: 1) the importance of physics, 2) teaching and learning methods.

Six (Table 1) and (Table 2) statements were used, aiming to define the change in attitudes towards physics and its teaching and learning methods. The statements were evaluated as follows on the 5 point Likert scale: 1 point indicates absolute disagreement, while 5 points indicate strong agreement.

Students completed pre- and post- educational questionnaires. All responses were anonymous. The response rate was 93.4% and 89.7 respectively in 2004/05 and 2005/06. Quantitative data analysis was used for this research (descriptive statistics, Wilcoxon signed ranks test for two dependent samples for data comparison within the group before and after the educational impact). The research data were analyzed using SPSS® 11.5 for Windows.

Results and discussion

1. The change in attitude towards physics and its importance

Physics teachers at university should foster the interest of non-science students in the study of physics. They should develop their understanding of physics concepts and laws by taking them from their 'alternative' or naive concepts toward scientific ideas; relate students' background knowledge with the new knowledge of biomedical physics; help them to realize that physics is not an isolated subject, but physics is everywhere, its knowledge helps to better understand the surrounding environment, it influences the activities of their future professional life.

As data presented in Table 1 show, statistically significant differences within the group before and after the educational impact were detected in four statements. The

comparison of the percentage ratings showed that differences were detected in the last two statements also. Students learned more about the influence of physics knowledge on their study program, they better understood the importance of physics for the profession they had chosen, and understood the importance of physics for perceiving their environment etc.

		2004/2005		2005/2006		
Statements	Before the educational impact, %	After the educational impact, %	Statistical significance,	Before the educational impact, %	After the educational impact, %	Statistical significance,
Physics is important for my specialty	47.0	70.8	0.002	48.8	76.5	0.000
University is able to provide information on application of physics knowledge in the chosen study program	56.3	92.7	0.002	57.8	87.4	0.009
Physics knowledge can help understand the physical processes in human body	40.6	81.3	0.000	44.5	81.7	0.000
Physics enables to learn simple experiments and to evaluate the accuracy of measurements	88.8	93.1	0.095	67.5	86.9	0.093
The correlation of topics in physics with the chosen specialty motivates for learning	52.0	81.7	0.004	45.3	80.1	0.001
Physics knowledge helps to better understand the surrounding environment	58.3	65.7	0.023	71.4	77.0	0.126

Table 1. The change in attitude towards physics and its importance

A large number of students perceived physics as the source of experiments; they understood the practical significance and the application aspect of knowledge. On the other hand, teachers should demonstrate that technologies are subject to change, so medicine professionals ought to know the fundamental principles.

The statistically significant differences after the educational impact for almost all statements show that students appreciate the efforts of teachers and the influence of SA as well, because they argue that social aspects of physics content motivate students for learning.

2. The change in attitude towards teaching and learning methods

This part of the study was aimed at investigating the effects of six teaching methods on student attitude toward them (Table 2). The statistically significant differences within the group after the educational impact were demonstrated the same methods: "Frontal work in laboratory" and "Seminar-discussion" during 2004/05 and 2005/06. A statistically significant difference was demonstrated for "Traditional work in laboratory" only for the 2004/05 year. It is clear that both approaches to laboratory work make significant contributions to student achievements in designing experiments and drawing conclusions. But the comparison of the percentage ratings showed that "Frontal work in laboratory" was more welcomed by students. Approximately half of the students appreciated "Traditional work in laboratory". This showed that students like face-to-face interaction with teachers. This is positive for the students' learning, since they can clarify all concepts and their understanding directly with the teacher.

But under our conditions: the short duration of lab classes (only 2 hours per week) and the large size of student groups, it is not possible to use this method effectively, or very often.

Nevertheless, we should notice that one of the most popular teaching methods among students still remains "Lecture". More than 80% of students during the last two years approved this method. It is widely recognized that in Lithuania lectures continue to dominate university science instruction as a very popular way of information transmission. Other factors that influence this attitude are students' learning habits and the fact that the first-year students are used to learning mainly in lectures.

		2004/2005		2005/2006			
Teaching/ learning methods	Before the educational impact, %	After the educational impact, %	Statistical significance, p	Before the educational impact, %	After the educational impact, %	Statistical significance, p	
Lecture	83.7	83.5	0.48	85.8	83.4	0.38	
Traditional work in laboratory	41	59.7	0.022	58	59.7	0.54	
Frontal work in laboratory	62.3	91.7	0.000	52.4	89.5	0.000	
Seminar- discussion	22.4	75.0	0.000	20.4	81.0	0.000	
Written course paper	22.4	22.6	0.515	22.5	27.6	0.902	
Project work	43.9	57.3	0.164	41.8	64.7	0.002	

Table 2. The change of attitude towards teaching and learning methods

No statistically significant differences were detected within the group for the methods "Written course paper" and "Project work", though the percentage ratings showed that approximately 22% and more than 50% of students respectively liked these methods. In our opinion, writing a course paper is not popular among students, because it requires much time and self-dependent work. The "Project work" is really an effective teaching method which encourages students' independent learning and collaboration. However, because of the short duration of the experiment, this method was not often applied in 2004/05. A statistically significant difference was indeed detected in 2005/06. This is explained by the fact this method was used more in 2005/06 than in 2004/05.

So, the assumption could be made that students accept active and cooperative teaching/learning methods that meet the principles of flexibility, socialization of educational learning environment as well as ensuring greater student autonomy and collaborative learning. In our opinion, that reflects the influence of the Systematic Approach on students' positive attitudes to active and collaborative methods.

Conclusions and future prospects

The project "Medphystrain" laid the groundwork for the redesign of the Biomedical physics course at Vilnius University. The new project "Dicort" will prepare the basis for e-learning in Biomedical physics.

Based on the research of the last two years, we argue for the assumption that the Systematic Approach (SA) had positive impact on students' attitudes to physics and its importance. Also we can state that the novel use of teaching and learning methods within the new educational environment (SA) demonstrates the advantage of enhancing students'

attitudes towards active teaching/learning methods and their positive attitudes towards collaboration during the physics course.

In this paper only a few parts of a fully comprehensive research study are presented. For a complete description of the development and evaluation of the new model (SA), please see reference [9]. In this research study it was not possible to make a comparative evaluation of the students' acquired knowledge. This research limitation possibly raised some obstacles for implementing the model and other results of our case study confirm this. We intend to carry out further collaborative research in order to determine in depth the strengths and weaknesses of this model.

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Emotional Activation and Increasing Motivation of Students based on Students' Cognitive Models

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ABSTRACT

One pedagogical technique aimed at emotional activation of students and increasing their motivation is the selective mobilization of attention and motivation' method, which based on the knowledge of typical misconceptions in the content of the teaching material and utilizes the theory of probabilistic prognosis.

This technique is effective in cases when the lesson deals with something about which the students have preliminary knowledge (even at the level of daily life), although for some of them this knowledge may be erroneous. At the very beginning of the lesson the students are asked a question related to the material to be taught. The question is formulated in accordance with the principle of multiple-choice, with characteristic misconceptions included among possible answers.

After the student made his choice, he is immediately provided with the correct answer. The discrepancy between the student's cognitive models (in the case that he is wrong) and the correct answer causes the latter to have an emotional reaction and increases his motivation and attention precisely at the time, when the teacher begins his discussion of the matter, that was misunderstood by the student. That is why we shall label this technique the Selective Mobilization of attention and motivation' Method - SMM.

INTRODUCTION

Teachers of physics, both in college and in high school classes, know well that teaching effectiveness is a serious problem. A number scholars refer to this problem (see references cited in the papers [1, 2, 3]) and mark that students may have many social goals in the class besides learning - such as making friends or impressing their peers, finding a boyfriend or girlfriend [1].

Although effectiveness of lesson is a function of several factors, to a large extent it depends on students' activity, motivation and attention. Naturally, the attention does not remain high throughout hours of studies. It varies, and these variations differ for every student. One student's attention flags at one time while other students' flag at others.

A "general mobilization" of audience attention ("I'm asking for your attention, I'm approaching a very important issue!") can be used by the teacher only 2-3 times during the lesson. If used frequently, this appeal loses its effectiveness and becomes senseless.

How can we, without resorting to "general mobilization", succeed in strengthening the attention of students at times when this is particularly important for them? How can we achieve such "selective mobilization" of attention?

It is known that control process in the teaching is significant and multidimensional. Most frequently this control process serves the function of evaluation, which is obviously important. This is the basis of the entire teaching method: after the subject is presented, questions are asked, and the students receive grades. Alternatively, at the beginning of the lesson the students are tested on the material previously presented, in order to review the material and then proceed with the subject studied.

We also use original short tests for the selective mobilization of attention.

In order to demonstrate this point we present here a brief test on the material of the present report.



Do you think is it worth giving at the beginning of a lesson a test on the materials that will be taught subsequently?

A) No, this is dangerous because it may encourage the student's feeling of inferiority.

B) No, it is a waste of time since the test should be given on material that has already been studied.

C) Yes, if the teacher knows in advance the types of the possible students' answers and immediately after the test provides the students with the correct answers.

D) No, since wrong answers chosen by the student may remain in his memory.

E) I don't know, or some other answers.

Please answer by using corresponding color cards

From our point of view, the answer is C, i.e. such test is meaningful, but only if the teacher provides the audience with the correct answer immediately and on the condition that the test has been appropriately composed. The rest of our report provides support for our point of view.

SELECTIVE MOBILIZATION TESTING OF STUDENTS' ATTENTION

We believe that the preliminary test must be both effective and informational.

To be effective, the questions of the test must be devised in a way that yields student answers within the shortest possible time. It is also advisable to employ a multiple-choice test, or one using graphics. Various methods can be used in order to determine rapidly the answers given by the audience.

One method is to provide the students with color cards to indicate their answers. This method has been demonstrated here. In this case a test may take place quickly even with a large audience (computer may also be used but this is not required).

To obtain the informational status of the test, it is important that the choice of answers should include (alongside with the correct one) the students' misconceptions related to the subject studied.

The experienced teacher is aware of these notions and misconceptions either from his own experience, or from relevant publications. For instance, the well-known Force Concept Inventory Test [6] can be used for mechanics lessons.

We used the examples here when teaching optics.

EMOTIONS AS A RESULT OF DISCREPANSY BETWEEN PROBABILISTIC PROGNOSIS AND ACTUAL SITUATION



Thus, the test takes no more than 3-5 minutes and does not depend on the number of students, while the card color provides the teacher with immediate general view of the ideas prevailing in this specific audience and indicates the misconceptions that are characteristic of this specific group of students.

THE THEORY OF PROBABILISTIC PROGNOSIS AND ITS APPLICATIONS

What else does the quick test at the beginning of the lesson provide?

Here we shall refer to the Theory of Probabilistic Prognosis developed by Joseph Feigenberg [3-5].

According to his theory, probabilistic prognosis is the ability to predict the events based on the previous experience, i.e. information stored in memory and prior conceptual knowledge, and the real actual situation, i.e. new information.

Using probabilistic prognosis one can create the scenarios or mental model relating to the immediate future: what will most probably happen in the nearest time.

Probabilistic Prognosis Theory assumes that the human emotional reaction is to a large extent connected with the fact of **actualization** or **non-actualization** of the probabilistic prognosis in the oncoming actual situation.

The **greater** the discrepancy between the prognosis and the reality stranger is the resultant emotional reaction.

By providing an immediate correct answer at the stage of preliminary test, we obtain different reactions of the students depending on the correspondence their answers with the correct one.

The reaction of the student whose answer does not correspond to the correct one is quite different from the reaction of the student who answers correctly.



If the answer is correct, the students gets the pleasant feeling of satisfaction ("Good for me!"), he can relax, his attention can even be somewhat distracted, since, in general, his understanding confirms with what is being studied.

If the student realizes that his answer is wrong, this results in a quite different emotional reaction. This reaction also appears because of the discrepancy between his answer and the answer provided by the teacher immediately after the test. The student whom answer was wrong, from one side, feels hurt "That's can't be right!" and, from the other side, tries to understand with interest and curiosity: "What is really happen here? Where is my mistake? "

This state makes the student concentrate his attention on this very part of the lesson. It makes him follow the discussion of this very problem, when the corresponding material is being delivered. Thus, his attention, unlike that of the student who gave the correct answer, will be concentrated at the "right moment".

Thus, a "self-tuning" of each student takes place according to the level of attention concentration. The student's attention is attracted just to the problematic place!

This situation can be referred to selective mobilization of attention, which is affected by the discrepancy between the expected and provided answer.

It is substantially important that the check up is anonymous. This eliminates the feeling of discomfort in the case of a wrong answer. At the same time, the student's attention is mobilized at the moment when the corresponding part of the material is delivered.

In fact the teacher is not interested specifically in who answered how. What is essential is that the student concentrates his attention at "the right place".

USING SECECTIVE MOBILIZATION CONTROL FOR TEACHING CORRESPONDING TO THE LEVEL OF STUDENTS' KNOWLEDGE

The teacher gets the impression (thanks to the color cards) of the approximate distribution of students due to the categories of their answers; i.e. he can obtain a qualitative evaluation of this specific audience.

It is important for the lecturer to be aware of students' prior knowledge. This enables him to be concentrated on conducting the discourse at the level that is the most appropriate one for this specific audience. Since preliminary testing helps the teacher gain information about the audience, this enables him to avoid the situation when the level of his lecture does not correspond to the prior knowledge level of the audience.

10-15 minutes before the end of the lesson, a test is given to determine the comprehension of the given material by the audience. The test is methodologically similar to the one at the beginning of the lesson.

During the rest of the lesson the teacher is supposed to correct the new ideas, taking into consideration any misconceptions appearing that need to be correct in regard to the new material in order to prevent transfer of wrong ideas to long-term memory.

CONCLUSION

The Selective Mobilization of Motivation (SMM) and student's activity is the cognitive thinking learning strategy that based on the Theory of Probabilistic Prognosis.

According to this theory there appears a sharp emotional reaction of the student in case of discrepancy between his answer and the right one.

The SMM occurs when a multiple-choice test, with the typical misconceptions taken into consideration, is given at the beginning of the lesson, followed by immediate presentation of the right answer to the audience.

We believe that the SMM learning strategy may influence to student motivation and cognition and help them to determine their goals and to reveal their beliefs.

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CONCLUSION

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Use of Humor in Secondary Physics

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Abstract

Teaching Physics to adolescents presents an interesting challenge. In addition to gaining and keeping students' attention, it is necessary to introduce difficult non-intuitive concepts to an audience with short attention spans and reluctance to employ higher order thinking skills. One approach which has proved successful in several Australian classrooms is the use of humour. Practical activities using non-standard equipment can encourage experimentation to test standard Physics models, whilst cartoon based worksheets, Flash animations and Power Point presentations enable reference to alternate, non-observed realities. For example, using the Physics model of gravity to predict the behaviour of a falling body and then comparing it to a Psychological model which involves the force of gravity depending on the knowledge and interaction of the observer engages student curiosity and develops a broader understanding of the underlying physical laws. In the competition to attract students to senior studies, any Physics course needs to be presented in a relevant and meaningful way to individual students. Humour is one way of achieving this without reducing the intellectual level of commitment needed for a high level of conceptual understanding.

Introduction

The aim of any Physics course is ideally to deliver information, promote thought, inspire curiosity and hopefully leave the student with a sense of awe and a desire to study further. Unfortunately in Australia the numbers of students choosing to study post compulsory Physics in schools is declining. Deckers and De Laeter (1997) found that over the last 20 years, Year 12 enrolments have increased considerably although there has been a decline in the numbers of students studying Physics since 1992. Physics at senior level has become a subject chosen only by serious, high achieving students who intend to move on to tertiary science studies.

A group of Secondary Schools in the outer eastern suburbs of Melbourne, Australia, participated in an Education Department project to determine the reason for the decline and attempt to reverse the trend. The decision on what to study in Years 11 and 12 is made by students in Year 10. The factors that influence their decisions were investigated and a program of activities conducted inside and outside the classroom to raise student awareness. The use of relevant contexts that engaged student interest succeeded in increasing the student uptake in senior Physics over the four year period. Humour was a key element in the programme.

Humour

Humour is subjective and personal. It can be visual, linguistic or physical. Humour is the interaction of familiar knowledge and experience with the unexpected resulting in something comical, amusing, or absurdly incongruous. Whilst the use of dogs for Psychological research is serious and unfortunate for the dog, the use of cats in Quantum Physics is both funny and painless for the cat. The application of Newton's Laws to elephants is appropriate, whereas to an observer bacteria may appear to obey a different set of rules.

Humour as a tool for modelling Physics can be used to engage students. It is difficult for a student who laughs at a joke to not become intellectually involved in the concepts challenged by the joke. The use of Humor as a pedagogical tool has been shown to reduce classroom anxiety, creating a more positive atmosphere and assisting the learning process (Berk, 1996, 1998; Garner, 2003, in press; Glenn, 2002; Hill, 1988; Pollio & Humphreys, 1996). Within the Physics classroom the reception of linguistic humour can be affected by culture, whereas visual Humour and physical humour are less culturally based and as such are more suitable for multicultural classes. Humour uses existing knowledge and then challenges or adds to it. Successful acquisition of new knowledge starts when old knowledge is adapted to match the new ideas and then integrated with it into procedural memory. Humour delivers information in short sound bites which is useful when the amount of information retained by students declines substantially after ten minutes (Thomson, 1972).

Humour in the classroom can be used as a social equaliser. Unfortunately in Australia there is a social attitude of extreme democracy. No one is supposed to be seen to be better than anyone else. The 'tall poppy syndrome" applies. Ridicule can be used as a weapon of attack, but it can also be used as a defence. Humour and self ridicule are socially acceptable ways for highly intelligent students to hide their ability and gain social acceptance whilst achieving top marks. Within the Australian classroom at both junior and senior level a joke is an instrument of social bonding as well as a tool for learning and the way that information is presented to students can impact on their learning (Berk, 1998).

Humour in Junior Science

Humour can be used to change attitudes. At junior level humour can be used to change negative or neutral attitudes towards Physics. Passive listeners are challenged to become active learners within a practical classroom using non standard equipment. 'Pop balls' and water bombs used to investigate energy changes in a practical class encourage less intellectual students to actively participate and then join in the mathematical analysis. "Students learn what they care about and remember what they understand." (Ericksen, 1984). The use of popular media to assess student understanding of Physics concepts and laws can be obtained through peer evaluation of the student's verbal scientific interpretation of short movie segments. Avi and mpg clips available on the web which show skateboarding accidents, car crashes and advertisements are invaluable in demonstrating to students why a working knowledge of Physics is invaluable. Practical work with Heath Robinson constructions into energy changes, lever action and Newton's Laws, or experimental investigations inspired by the *Mythbusters* TV show using the familiar "Busted-Proved" format and competitions of the "Egg Drop" and "Bungee Barbie" type are not only good in a learning context. The activities change student attitudes towards participation in Physics. Visible bizarre practical work has an interesting side effect as students sitting in other classrooms completing textbook exercises watch the fun and laughter shown by the junior Physics students and their attitudes to science are changed in a positive way.

Humour can be used to increase understanding. At junior level cartoons such as Road Runner can assist students learning Newton's laws to appreciate the relationship between observation, prediction and event outcome. Watching animated clips encourages students to think as they laugh, especially if it is after an introduction to the Newtonian view of the world. Discussions and assignments afterwards lead to a greater in depth analysis of Newton's Laws than obtained by answering comprehension exercises from a textbook. This also promotes discussion by the students of the physiological, psychological and philosophical aspects of the relationship of the observer to the observed phenomena. So the introduction of the concept of differing frames of reference to junior students becomes obvious. This approach has proved particularly successful with students showing low self esteem and an unwillingness to voice an opinion in case an incorrect answer leads to peer ridicule. The use of humour in the practical work involving the use of strange objects to monitor and measure or the use of a familiar object used in a bizarre way overcomes student reticence to engage in learning. When the object of the practical exercise is a red plastic Superman rotating overhead, or a weighted black plastic spider dangling from a thread, or a green plastic frog in a lettuce spinner for centripetal motion, or a radio controlled hotrod car roaring down a corridor, students are not only willing to actively engage in the practical activities but they see it as fun to engage the thinking processes needed to analyse the situation. With juniors the opportunities presented to them are seen as 'cool' or boring. Not to participate in measuring the velocity of the hotrod up the corridor is seen as boring. Communal laughter helps in collaborative learning and collaborative learning may be the fastest way to gain conceptual understanding.

The present adolescent obsession with computer gaming leads to a desire amongst even non-science students to investigate real world physical laws to develop more realistic modelling using 3-D Rag-Doll animation. Students' awareness of comical alternatives to standard Physics laws (such as the Cartoon Laws of Physics) help take Physics from the "too hard" basket to a recognition that Physics laws have everyday relevance and convince students that it is worth investing the effort required for better understanding. Assessment of the understanding gained can be achieved through normal testing using written contextual questions requiring worded answers and step process calculations, or by employing more imaginative participation. The physical construction of a model (which may or may not be required to demonstrate the actual working process) can be used. Alternatively the students can put together a cartoon animation for a visual representation modelling correct or humorously incorrect Physics. Standard tests can be written employing cartoons as a model and directing the questions to the student's perception of the cartoon. The use of cartoons is particularly helpful in showing up student misconceptions and areas of incomplete understanding. The use of humorous cartoons in tests is also useful in giving the gifted students the opportunity to excel in private without fear of a 'tall poppy' attack. For the low achiever the cartoon is an opportunity to show their colouring-in skills.

Humour in Senior Science

For humour to be most effective as a teaching tool at senior level, it is best used to reinforce an idea or introduce a new one after the framework of laws and relationships have been introduced. The introduction of new concepts to a senior class and worked examples showing ideal situations with two controlled variables provides a comfortable but boringly unrealistic representation of the real world. If this is followed by a worksheet containing a cartoon which either defies or exaggerates the concept together with a set of questions designed to promote discussion, student laughter signals the start of the assimilation process. The James Bond movies, *Speed, True Lies, Matrix* and many other action or science fiction movies lend themselves to a critical analytical study using formula, assumptions and approximations. This approach allows less able students to grasp concepts at a level with which they are comfortable and give verbal presentations to their peers. The outcome is always positive because even when the level of Physics explained is not high or contains errors, the other students are appreciative of the effort and their comment then centres on the choice of movie segment.

Using humorous situations for practical work (such as the use of water pistols for two dimensional vector analysis and rotating bats for centripetal motion) provide a more realistic, more sophisticated model. It gives the opportunity for students to test their understanding of the variables responsible for determining an outcome and assists the students to postulate a more reliable model. "All genuine learning is active, not passive." (Adler, 1982) Frivolous contextual examples help to counteract the reticence in high achieving students. Their fear of failure in front of their peers can prevent them from asking "dumb" questions or giving a "stupid" answer. A dumb question in response to a frivolous context is seen as a positive humorous response. For student assessment the use of humorous cartoons in written tests is good for showing up student misunderstandings, but on an exam the very nature of the open ended thinking can be counter productive. It can lead to too much time being invested on thoughts and answers which are not rewarded with marks, especially when the examiner is only looking for one set response to a question and there is such rigidity in the system that correct alternate answers are punished by not being credited.

Conclusion

Physics can be seen as an analytic science, but its strength is wider than that. The analysis it engenders results in the design of new experiments, development of new models and discovery of new questions. For students it is valuable to change the pattern of learning from memorizing text book style questions and occasionally to break with the Euclidean model and to employ humor. The importance of studying Physics is not immediately obvious to adolescent students. Their first formal encounter with Physics in junior science can be a negative experience. For students it is valuable to change the pattern of learning from memorizing text book style questions, to break occasionally with the Euclidean model and to employ humor. Humor has been found in at least one study (Carroll, 2000) to change student attitudes towards Physics, increase active participation and encourage more students to study senior Physics. Playfulness in interpretation leads to a confidence with experimentation and greater self questioning. A deeper understanding of the physical laws can transform simple conjecture into invention.

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An interdisciplinary curriculum for high school students involving Physics education

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Abstract

In the context of the prevailing challenges in education, one of its crucial goals is to endow the students with an ensemble of functional competencies. Therefore, educators across the globe have been developing new strategies in which active learning plays an important role, creating a student-centered learning atmosphere. That also demands a transformation of teachers involved in edifying innovation to introduce new curricula adapted to the specific situations. Our proposed curriculum takes into account both the contemporary trends of education and the necessary state of affairs for its implementation. It is an interdisciplinary approach in terms of CDIO (Conceive, Draw, Implement and Operate) that can be adapted and implemented to the high school level. We have tried to initiate, within an optional class, a project based-learning atmosphere, involving the subjects of Physics and Informatics under the guidance of two teachers skilled in the respective fields. This paper presents the input, the process and the possible output of this curriculum along with other issues related to our purpose.

Introduction

Over the years, the concept of teaching has been modified to introduce a comprehensive framework with the unique aim of exclusive involvement and capitalization of students abilities. In the modern education, "active learning is a key element expected to increase student motivation, commitment and retention" [1].

It is known that, in the traditional approach of teaching the main active personage is the teacher who is supposed to deliver lecture while students listen and observe the lecture and pay deep attention to take notes. This teacher-centered model of teaching has become today not only unfashionable, but also less efficient. The idea of active learning has its roots as far back as 490 BC, when Socrates used problems and questions to guide students to analyze and think about their surroundings [2]. Today, many progressive educators have developed and emphasized this method, applying it at all levels of education. Instead of being passive recipients, learners have become involved directly in the process of teaching. This method bestows a higher responsibility on students, though it does not relieve teachers from their obligations. Moreover, students prefer active learning techniques comparing to the traditional methods, because they entail more spontaneity, flexibility, diversity and just amusement [3].

Another modern concept is interdisciplinary education. True interdisciplinary education was developed today by many colleges and universities, who demand that researchers should not be stuck in traditional subjects. The new interdisciplinary programs are taught by at least two teachers from each of the participating disciplines.

Contents and reasons

Starting from these two basic concepts ('active learning' and 'interdisciplinary education'), we have conceived an innovative curriculum for the students in the last year of study (12th

grade) in a high school in Romania, which intends to connect their knowledge in Physics and Informatics.

A brief overview of our innovative curriculum is shown in figure 1.

This curriculum is addressed to mathematics-informatics profile and the class is scheduled as one hour per week as an optional type of class on any integrating topic. This type of curriculum is a form of "Curriculum at School Decision (CSD)" that includes:

-new competencies of integrating and transferring knowledge between common disciplines;

-new content which connects at least two disciplines.

The role of a single teacher is replaced with a team of two teachers who assume different responsibilities according to their abilities, interests and experiences [5]. The target of the curriculum is to let the students conceive, draw, implement and operate, in a CDIO framework adapted for a pre-university level, a set of lessons focused on the first level of studying Physics (6th grade). The concept of CDIO has been incorporated by many engineering educators in universities in order to reconsider and develop both the curriculum and the teaching methodology for undergraduate programmes [6]. We considered that CDIO system can be rather easily adopted in the last grade of the high school with some specific adjustments.

This curriculum concerns a laboratory which is supposed to encourage and engage the best students with in-depth knowledge both in Physics and IT by the process of creating exciting didactic materials for teaching 'basic concepts in Physics'.

It is organized in following two modules according to the semester repartition of hours:

The reasons for developing this new curriculum are:

- interdisciplinary approaches in Romanian high schools are weakly represented;
- the students in mathematics-informatics profile, especially in the final years, are very interested in some programs like Flash, Swish, Visual Basic, HTML, but have few opportunities to apply them in the school in solving practical problems;
- many of the students from mathematics-informatics profile are directed toward engineering profiles in their future academic studies and Physics is also a subject in which attract them;
- engaging students in remembering, thinking and rendition of some basic concepts can both strengthen their knowledge and help them to evaluate their achievements [7];
- working in groups, students can develop abilities to take the responsibility of any given assignment in university level;
- students have total freedom within these lessons and that offers them the opportunity to develop their individual skills in some areas which are not included in standard curricula;
- processing abstract ideas in concrete material affords the opportunity not only of a long term involvement of students but also of a feedback which obliges them to reflect upon their works, to raise new questions, to criticize their "products" and finally to augment their results that ultimately give them satisfaction.





This curriculum is a part of the Romanian reform of education which was conceived in 1997 and announced as a number of collective measures, among which the curriculum reform is the first one. It is clear that in any project of curriculum change a main role is detained by the teachers who have to adapt and rethink their activity in order to optimally conform to the educational objectives. The point of starting to implement the two modules was the competencies which are expected to be obtained by following the proposed modules. In addition, we considered the following:

- human and material resources in a school are better known by the teachers from that school;
- in the light of a de-centralized education, it is absolutely necessary that each teacher be a dynamic player who offers, according to his pedagogical and professional abilities and personalized curricula answers to queries from his students
- a specific curriculum increases the democratic participation of teachers and students in taking decisions regarding the content of school education as well as entailing the enhancement of the school quality.

Moments of the project

Preamble

In this part, each module is depicted from which the students can be acquainted with the goals and content of the curriculum. The teachers present also the benefit of the achievement of Physics lessons on computer. Examples are given through some presentations which are not supposed to be modules, but starting points or sources of inspiration. At the same time, the teachers provide the necessary materials (books of Physics, CD's, list of references). Two hours are allocated for the teachers of the team of educators, to present their own specific roles and recourses. In this "moment" the students are told that they will work in teams during the whole module. A team is constituted by five students ("experts") who possess complementary abilities and who contribute to the achievement of the project. The "experts" have to be skilled in: Physics, IT programs, editing, drawing and compilation. For the first semester the final objective for each team of students is to achieve a poster and a Power Point presentation for one of the following chapters: physical quantities, mechanical, thermal, electrical, optical or magnetic phenomena. The same topics may be transposed as sophisticated lessons in a suitable computer device which will form complete educational software for teaching Physics in the future at any appropriate level.

Semester	Specific comments	Moments of the projects	Time (h) Assessment
First Sem	ester		
	-recognizing, recalling,	Preamble	2 -systematic
	interpreting, exemplifying,	Team formation and	1 monitoring of
	classifying, summarizing,	repartition of the	the students
	inferring, comparing,	topics	behaviors
	explaining, analysis,	Conceiving and	4 -self assessment
	synthesis concepts in	drawing lessons	-oral presentations
	Physics	Implementing and	4 -papers, posters,
	-using internet and other	operating	educational CD
	resources to obtain	Revisions and oral	3
	information	presentations	
	-developing oral presentation		
	skills		

Table 1: Annual scheduling

Second semester		
-enhancing IT skills	Preamble	2
-implementing IT notions	Reformation of the	1
in conceiving Physics	teams and repartition	
related materials and lessons	of assignments	
-developing the scientific	Conceiving and	8
language	drawing lessons	
-developing of critic and	Implementing and	10
self-critic appreciation skills	operating	
-experiencing team work	Revisions and oral	3
	presentations of the	
	educational CD	

Team formation and repartitions of topics

The students are supposed to think one week about their preferences and, with the help of the teachers they will form then the five-group. Each team will have a leader who is openly elected/selected both by the teachers and the students. Then, the teachers assign a topic for each group. This is just the moment when a brainstorming is going to be started.

The students have to revise the general notions related to their topic in Physics from a school book, as homework. For the second semester it is better to keep the same groups, but in special cases students can join from a group to another, according with their abilities and preferences.

Conceiving and drawing

The class is unfolded in the laboratory of informatics where the computers are connected to the internet. The teachers, along with the students sketch the content of a lesson which does not have to be mandatory standard one (giving students a certain freedom in accomplishing their tasks). Generally, each lesson contains an eloquent title, preferably a motto which can be a catchy one, textual content, virtual experiments or animated images (for the projects in the second semester), conclusions, short stories related to the topic, summary and tests. The students along with the teachers establish the technical details about the applications used for creating the projects. In the second semester, this is the "moment" when the teachers and students discuss also about the accumulation of all the projects in unique educational software and the interface from which the lessons are launched. The responsibility of gathering all materials is ascribed to a student.

Implementing and operating

At this point the students, assisted by the teachers, pass properly to creating the lessons on computer. The teachers have to survey the activity and verify the accuracy of the scientific content. They also help students to solve some problems which could appear during this process and help to estimate the time that is to be allocated for every step. Each project must be accompanied by an electronic handbook. Being allocated only one hour per week, this discipline is based also on homework. For the second module, the teachers along with students elect a leader, expert in IT, in order to accumulate all lessons and to insert an accessible and friendly interface for launching them. The group leader will obviously work under teachers' guidance.

Revision and oral presentation

Each project will be examined and tested. A project will be transferred to one or two other teams for a peer review to mend any disfunctionalites. At the end, the teachers verify each project and then the students present their work in an open meeting together with other students and teachers.

Conclusions, discussions and expectations

In the context of the huge impact of information, the educators taking responsibility to find ways of catching the learner's attention is a crucial key for successful implementation of the process. On the other hand, the development of students' abilities demands a dynamic system of education. Moreover, there is a rapid progress in sciences and that demands a continuous readjustment of school curricula to the new needs of society. Our proposed curriculum takes into account these requirements. In addition, the CDIO concept, applied in pre-university level, offers a proper frame to reach to our target.

We consider that our curriculum is one that brings and applies active learning strategies, connecting more disciplines, fostering creativity and enabling students to become more responsible for their own instruction. In addition, cooperative learning appears to be a promising method by which students can simultaneously achieve both academic and sociomoral skills [8].

We are conscious of the difficulties of fulfilling such a curriculum in the current educational environment. The main problems could be:

-inclusion this curriculum in the present legal frame

-disinclination of some students and, perhaps, school staff

-lack of experience in such interactive curricula regarding the teachers who will direct it

-assessments of the students in this class

-collaboration/communication in teams (in general, except sport class students are not accustomed to work in teams), possible tensions;

-the respect of timetable in accomplishing of the proposed software, etc.

Our positiveness about the success of this proposed curriculum is based on students potential, teachers enthusiasm and the proper learning environment (lab with PCs and internet connection).

We expect that the efficacy of these lessons to be reflected in:

-captivation of students attention

-relevance of previous knowledge and capitalization of it

-increase of confidence

-exuberating satisfaction [9]

The positive features and expectations of this curriculum encourage us to conclude that it is worthy of implementation. We are convinced that, with such a great input, the success of this new curriculum can be achieved, both the teachers and the students being winners after experiencing this challenge.

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Multi-Media in Physics Education

Professor Icetein learns how to ice-skate

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Abstract

We present a video that can be used both in physics education and as a scientific popular mean.

In this video a physics professor named Icetein, is trying to learn how to ice-skate. So he begins by analyzing the precise movements performed by the athletes while practicing. Each exercise can be viewed from a physics point of view that is briefly explained. Ice-skating provides a particular low-friction situation, so it can be used as a special laboratory in which the distance between reality and the physical model is shortened. Many laws of mechanics are found out and described in a simplified and pleasant way. Some evaluation made by teachers is presented.

Introduction.

The goal of the movie "Professor Icetein learns how to ice-skate" is to present some physics laws in a very simple and enjoyable way. Our target has been to show to the public that physics is everywhere in everyday life and that it is not too difficult to understand it. Here we would like to discuss how a video like the present one can be used in a class. We are convinced that videos can be very useful in physics education, because:

- they allow to show something which is not possible to show in a school lab;
- they allow to observe various situations in a brief time;
- they induce to discuss on several topics;
- they can be easily remembered if something very peculiar is presented;
- students get the explanations from someone who is not their teacher.

Even though teachers are in general favorable to using movies, not many suitable ones are available. We hope that our video can be both a useful educational tool and a starting point for other similar products.

The video.

The main idea in realizing this video is to link physics to sport. There is a lot of physics in any sport, so we had to choose one. Our choice fell on ice-skating for the following reasons:

- the ice ring is a special lab in which the distance between reality and the physical model is shortened
- ice-skating allows to discuss many aspects of physics of motion
- ice-skating is not too difficult to be video-recorded (much simpler than skiing, or sailing, for example....)
- it was realized in the WYP year 2005 and its distribution started in the same year of the Winter Olympic games Torino 2006
- the support of the ice-skating club of our town has been enthusiastic.

This video is a sort of story: how to learn to ice-skate with the help of physics. The man to be trained is professor Icetein, a character which reminds Einstein. Icetein appears in several cartoons, making the movie more enjoyable.



Since there is really a big amount of physics in ice-skating, we decided to restrict our analysis to mechanics. The topics presented concern the principles of dynamics, the centripetal force, the circular uniform motion, the conservation of momentum and angular momentum. Why it is possible to ice-skate and how the Zamboni machine works (the machine that restores the ice surface) are discussed as well.



How to use this video in a curriculum

Since the video mostly avoids formulas and difficulties, we suggest that it can be showed to students before they afford any mechanics. In this way, students can become more curious and they will be persuaded that it's worthy to study physics...Physics is everywhere!

After they know some physics, the video can be seen again, in order to better understand what is going on. Another possibility is to show the movie in different moments, choosing the chapter of interest in a particular moment of the curriculum.

Evaluation.

Up to now it seems that the DVD has been appreciated both by popularizers and teachers, at least in Italy.

Regarding the popularization, we did not make a survey, but we would like to note the following: the video is now proposed, cut in episodes, in the web-site http://scienzapertutti.lnf.infn.it/index1.html; during the Winter Olympic games, few minutes of it has been shown on the Italian TV; some (Italian) science museums have asked to use it for their own purposes.

On the physics education side, we did make a survey. We sent a survey form to the teachers aiming to check both their satisfaction from a professional point of view and the way they used this video. It turned out that the teacher seemed to like it (see tables 1 and 2), even if a few of them asked for a deeper explanation (but, on the contrary, a few asked for a simpler explanation).



Most of the teachers used the video when they concluded mechanics classes. They just wanted to check if the students could understand what is shown on the basis of what they had previously studied (tab3). Most teachers recognize that this video can be a good popular scientific mean, but still they don't want to use it in this way (tab.4). It seems that physics education and science popularization are two complete different worlds.



Conclusion.

We think that movies like the present one can be useful in physics teaching. We hope that teachers will become less flexible in their teaching, letting their students to enjoy physics. We wish that other similar products will be realized and that they will play a more important role in physics education.

To have more information or to ask for the DVD, please contact one of the authors.

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The Use of ICT in Higher Education: Multimedia in Physics Teaching

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Abstract

From the early eighties it has been recognized that computers might be beneficial in the teaching and learning process in Science Education. A lot of new ideas about applying Information and Communication(s) Technologies (ICT) emerged, inspired by technology itself and by new views on education and schooling. An excellent example is the 'Virtual University of Bavaria' (VHB), opened to the public via Internet in May 2000. The VHB provides various multimedia-based lecture courses contributed by Bavarian universities. The Physics Education Departments of the Universities of Augsburg and Erlangen-Nuremberg have jointly developed the course 'Multimedia in Physics Teaching'. This virtual lecture is intended for teacher students to acquire knowledge and special skills as well as for professional teachers interested in modern teaching methods. Ideas and intentions of the project will be presented; contents and the educational plan of this lecture will be explained in detail.

Introduction

In 1941 Konrad Zuse, a German engineer and computer pioneer, built the Z3, the first working programmable, fully automatic machine, that we nowadays call a computer. In the 1980s computers were first used to support the teaching and learning process in Science Education and in the 1990s the Internet became important.

Exactly 60 years after Z3 was built, the 'Virtual University of Bavaria', in German 'Virtuelle Hochschule Bayern' (abbreviated: VHB), was founded – using <u>Information and Communication(s)</u> <u>Technologies</u>, inspired by new views on education and schooling.





The 'Virtual University of Bavaria' (<u>http://www.vhb.org</u> (24.8.2006)), opened to the public via Internet in May 2000, is a network of all 41 Bavarian universities – governmental universities, universities of applied sciences and other universities (see Figure 2). It is based on collaboration of these member universities, sharing their knowledge and their expertise. It promotes online learning and teaching and develops compatible information infrastructures. The students of the VHB have access to high-quality multimedia-based courses, independent of time and location; therefore they have to enroll in one of the member universities. The objectives of this institution go along with the fast change of knowledge and the need of lifelong learning. It is complementary to the regular university lectures. Hence it allows access to education of an equally high standard in all regions of Bavaria.

Fig. 2. VHB: A network of 41 Bavarian universities.



Currently, about 170 training courses in eight different fields ('Informatik', 'Ingenieurwissenschaften', 'Lehramt', 'Medizin', 'Rechtswissenschaften', 'Schlüsselqualifikationen', 'Soziale Arbeit' and 'Wirtschaftswissenschaften') are offered.

Within the field 'Lehramt' the University of Augsburg and the University of Erlangen-Nuremberg with its institutes provide several courses for teacher training such as the 'Multimedia in Physics Teaching', a cooperation-project, developed by Prof. Dr. Helmut Hilscher, University of Augsburg and Dr. German Hacker, University of Erlangen-Nuremberg, now teacher at grammar school (Hardenberg-Gymnasium, Fürth, Bayern).

Lecture 'Multimedia in Physics Teaching'

Target Group

The virtual lecture 'Multimedia in Physics Teaching' is intended for teacher trainees to learn special skills as well as for teachers by profession interested in further education.

Ideas and Intentions

In accordance with the regulations of the teachers' 'First State Examination' in Bavaria ("Lehrerprüfungsordnung für das Erste Staatsexamen", LPO I) the lecture pursues two objectives:

first to provide *both* teacher students *and* teachers in service with the up-to-date knowledge about multimedia (keyword: professional competence) and to enable them to use multimedia in a didactically and methodically meaningful way in order to improve teaching and learning (keyword: teaching skills),

second to illustrate, how students at school can experience the use of multimedia in a self determined learning process, and how they can improve their 'Media Literacy' which finally leads to more independence in lifelong learning.

The virtual lecture comprises five thematically independent units, so-called modules (see Figure 3), which cover the actual state of knowledge in the field of using multimedia in physics teaching:

- (1) Computer Simulations,
- (2) Digital Video Analysis,
- (3) 'Interactive Screen Experiments', a new representation of experiments with multimedia-based technology,
- (4) Data Acquisition and
- (5) The Internet.

Fig. 3. 'Multimedia in Physics Teaching': Five independent modules.

Module de	r Vorlesung	
Modul 1:	Simulationen	
Modul 2:	Videoanalyse	
<u>Modul 3:</u>	Interaktive Bildschirn	nexperimente (IBE)
<u>Modul 4:</u>	Messwerterfassung	
<u>Modul 5:</u>	Das Internet als elekt kations- und Informa	ronisches Kommuni- tionsmedium

Contents

Let me briefly present just the two modules 'Computer Simulations' and 'Digital Video Analysis':

The module Computer Simulations introduces the idea and the benefit as well as the use of simulations and animations at school on the basis of various interactive examples.

To **see** the optical phenomenon of a rainbow, you need raindrops in front of you and the sun behind of you, shining on the raindrops. On good terms, you can even observe two rainbows: the more intensive 'primary rainbow' and the less intensive 'secondary rainbow'.



Fig. 4. Phenomenon of a rainbow - 'real' photo (A.Fösel).

To **explain** this phenomenon, you can read a textbook, but you will much more understand, if you 'construct' the rainbow by yourself, respectively by a good simulation.

So have a look at a tool developed by Dr. Helmut Dittmann from the University of Erlangen - 'regenbc.exe' (Dr. Helmut Dittmann: http://www.didaktik.physik.uni-

erlangen.de/download/winprog/regenbc.zip (24.8.2006)):

The screenshot (see Figure 5) from 'regenbc.exe' shows a result of the simulation on the left and a photo-clip of a 'real' rainbow on the right in comparison. On the left you can see the angular scale with a lot of dots, each of them indicating an incident ray of sunlight. The scale shows the zones appearing after one and after two reflections. As a result you can see the primary rainbow and as well the secondary rainbow. On the right you can see a photo-clip of a 'real' primary and secondary rainbow in comparison.



Fig. 5. Screenshot of a primary as well as a secondary rainbow: Simulation and photo-clip in comparison.

The computer-aided analysis of video-clips, which are normally specifically recorded for the purpose of teaching by means of a digital video camera or an analogue video camera in order to be digitised afterwards, is an example for 'Multimedia in offline mode'. The module Digital Video Analysis provides theoretical basics in video capturing and in using video analysis software to analyse motion. The handling with characteristic video analysis software, for example 'DIVA' (C. Dziarstek (Prof. Dr. Helmut Hilscher), University of Augsburg; source: Multimedia Verlag Physik: <u>http://www.multimedia-physik.com/index.htm</u> (24.8.2006)) and 'VIANA' (Thomas Kersting, University of Essen: <u>http://didaktik.physik.uni-essen.de/viana/</u> (24.8.2006)) should be practised by means of video-clips which can be downloaded by VHB-students.

Educational-didactical Plan

The educational-didactical plan of 'Multimedia in Physics Teaching' follows the intentions of the virtual course already mentioned: First of all, each module offers the theoretical basics. Subsequently various examples explain those basics and relate to what you come across in everyday life. Students and teachers make full use of the multimedia-based possibilities of virtual lecturing, as experimenting interactively, giving explanations by 'mouse-click', cross-linking by hyperlinks. For each module there exist exercises: Some of these are compulsory for VHB-students, they are controlled by tutors; some exercises are voluntary and just for self-control.

Practical Training

Because one of the principles of the lecture is learning by doing, there is a practical training part of the lecture. VHB-students spend one day at university, *doing* data acquisition and *doing* digital video analysis work.

Concerning video analysis work, the students record video-clips by means of an analogue video camera. For video capturing they apply the software 'WinDV' (http://windv.mourek.cz/ (24.8.2006)), a small and easy to use Windows application for capturing videos from DV device into AVI-files and for recording AVI-files into DV device via FireWire (IEEE 1394) interface. Subsequently they use the free video capture/processing utility 'VirtualDub' (http://www.virtualdub.org/ (24.8.2006)) for applying a so-called 'deinterlace filter' and for compression.



Fig. 6. A tennis-ball falling. Screenshot from a digitised video.

The students analyse the process of motion by means of the video analysis software 'DIVA': The acceleration due to gravity 'g' is determined via experiment and video analysis (see Figure 6-8).
Fig. 7. A tennis-ball falling. Screenshot from video analysis software 'DIVA'.





Fig. 8. A tennis-ball falling. Screenshot from video analysis software 'DIVA'.

Summary and Future prospects

Let me sum up: The virtual lecture with its educational-didactical plan just mentioned suits well to provide teacher trainees and teachers by profession with professional competence and didactic skills, to illustrate teacher trainees and teachers by profession, how pupils can experience the use of 'Multimedia' in a self-dependent learning process, and how pupils can improve their 'Media Literacy' which finally leads to more independence in lifelong learning. The students of the VHB have access to high-quality courses at any time or place. The disadvantage of ,missing contacts' between the students is reduced by a so-called 'Forum', a kind of a (virtual) chat-room, where VHB-students can discuss concerning the virtual lecture and by the practical training, where they do actual experiments.

As scheduled there will be much more money for tutors and other institutions of the universities as soon as tuition fees will have to be paid at German universities.

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Theatre, Film and Show techniques for Science Education

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Abstract

In this article, we motivate our interest in theatre, film and show techniques for science education and explain our methods with one specific example taken from the DVD-project "QED – Matter, Light and the Void".

Introduction

Mathematical formulas are like pieces of music. They need to be *performed* to come alive.

Mathematics is a language which is needed to communicate observations and findings in physical research. But are mathematical formulas the best medium to reveal the fascination for the laws of nature to students? The answer to this question is obvious using the analogy to a piece of music: Are music scores the best medium to reveal the fascination for music?

Obviously, the answer is no. A fascinating and *emotional experience* of music can only be achieved if music comes alive through *performance*. It is this experience which motivates pupils to learn the technicalities, that is, reading and understanding music scores.

How can we motivate pupils to learn abstract, mathematical models in physics? I claim that theatre, film and show techniques are important to create a fascinating and emotional experience of science. It is this experience which motivates pupils to learn the language of science, that is, mathematics.

The DVD and internet project "QED - Matter, Light and the Void"

The interaction of electromagnetic radiation with electrons and positrons is successfully described by quantum electrodynamics (QED). A fascinating history of research has led to the success of this theory. J. Schwinger, one of the fathers of QED, describes the development of the theory as follows [1]

"Only when the theory is finally frozen in the textbooks can one speak of the 'physicist's conception'. At any interesting moment of the development of the theory, there are discordant viewpoints of individual physicists."

These discordant viewpoints stem from our limited understanding of nature. Our mathematical models are not the reality but only an attempt to describe some parts of reality. Only if the predictions of a model agree with observations in nature, does the model survive and develop further.

Mathematical models reflect concepts and ideas the scientist has for his view on nature. Even if the mathematical implementation of the model becomes very complicated, the underlying concepts and ideas can be simple and beautiful.

How can we teach pupils at high school the simple and beautiful ideas which stand behind the mathematical model without teaching the complicated technicalities of the mathematical model itself?

We approach the problem how the simple and beautiful concepts underlying quantum electrodynamics (QED) can be explained on three levels:

Level I: A puppet animation movie about QED. In five chapters, the concepts behind the theory are introduced without mathematical equations. Here, we use the following methods:

- (i) Two puppet characters discuss the question what light is and debate different models to explain their experimental observations.
- (ii) Visualization of the models and underlying physical concepts using modern computer graphics.
- (iii) Performance of experiments, comparison with the models, and once more: discussion of the results.



Level II: 30 short clips (3-4 minutes each) in which the intuitive concepts introduced in the puppet animation movie are related to mathematical equations.

Level III: Further explanations of the models introduced on the DVD are provided through the internet on the webpage "Cinema and Science", (<u>www.cisci.net</u>). This material enables teachers to use parts of the movie in classroom.

The EU-funded project "Cinema and Science" (CISCI, <u>www.cisci.net</u>) combines two media, the internet and the DVD to raise the interest of young people for science. The website with high-school suited explanations for more than 100 movies will be launched

in December 2006 in a cooperation of 7 European countries. The movies range from Hollywood blockbusters with scientific and pseudo-scientific content to educational movies like "QED – Matter, Light and the Void":

In classroom, short sequences (3-4 minutes) of the movies can be presented to introduce a topic and to motivate the scientific analysis. From the DVD "QED – Matter, Light and the Void", more than a dozen short clips can be used in classroom to introduce the physical properties of light.

The commutator

The so-called commutator is of uppermost importance in physics. In quantum mechanics, the position x and the momentum p of a particle do not commutate, meaning that "x*p" is not equal to "p*x". Rather, the commutator x*p - p*x is proportional to Planck's constant h. Likewise, creation and annihilation operators of photons in an electromagnetic field do not commutate.

In level I of the QED-project, the commutator does not occur explicitly. However, the consequence of the non-commutativity of position and momentum is shown in the staircase model of the atom (Chapter IV). Furthermore, we introduce a simple model of the absorption and emission of light quanta (Chapter II).

In level II of the QED-project (Chapter IV b), a simple mathematical model of the commutator is introduced, which will be discussed below.

In level III of the QED-project, additional educational material about the commutator is provided on the webpage <u>www.cisci.net</u>.

How can we perform the concept of the commutator? The model which we propose is the following: We use an empty glass, a bottle of water and two operations: The first operation turns the glass upside down (described by the operator U) and the second operation pours water from the bottle (described by the operator W).





The operators U and W are applied to a glass. It is a simple (and funny!) exercise to show that the two operations do not commutate. Before any equations are introduced, pupils can experience the effect of these operations by using a real glass and a bottle of water. Doing so, the fact that ordering is important if operators are applied to a state emerges naturally.

It is also possible to assign the role of the operators U and W to two pupils and to show the noncommutativity as a little on-stage demonstration.

After this demonstration, pupils feel motivated to learn how this experiment can be translated into mathematical equations. It is fascinating that there exists a fundamental relation between *mathematical equations* and the *experiment*. Once the mathematical model is introduced, we can compare *predictions* which follow from the equations with *experiments* which are performed on the glass with the operators U and W.

We introduce three possible states of the glass:

- 1.) Glass upright, empty
- 2.) Glass turned upside down, empty
- 3.) Glass upright, filled

Operating with U and W changes the state of the glass from an initial state to a final state. We can introduce for U a 3 times 3 matrix which shows all possible initial states (line of the matrix) and all possible final states (column of the matrix). The final state which emerges when applying the operator is defined by the entry "1" in the matrix, all other entries are "0". With this definition, the operations U and W are represented as two different 3 times 3 matrices. Using this mathematical representation, we can compare predictions of the theory with experiments, and vice versa.

The experiment tells us that the operations U and W do not commutate. Translated into mathematical language, this signifies that the matrix product U^*W - W^*U does not vanish. Indeed, the calculation shows that this is the case.

In level III of the QED-project, we introduce a basis transformation and diagonalize the matrices U and W. It is interesting to discuss the experimental realization of these mathematical calculations, which is rather unexpected. The full text of level III can be downloaded from www.sciencemotion.de

More examples for pupils' exercises are:

- 1. Calculate U^2 and W^2 using matrix multiplication. Compare the resulting matrices with the experimental realization of the U^2 and W^2 operators.
- 2. Discuss the inverse of the operations U and W both experimentally and mathematically.

3. Find non-commuting operations which are isomorphic to U and W

Summary

The DVD and internet project "QED – Matter, Light and the Void" is briefly introduced in this article. The project is part of the EU-funded initiative "Cinema and Science" (www.cisci.net). Our aim is to find possibilities to perform mathematical equations, that is, to a give direct, intuitive and emotional access to the underlying ideas behind the abstract formalism. The backbone of the project are computer graphics and character animation techniques.

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Relation between Physics Students and Computers in Developing Countries: A Case Study from Sudan.

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Abstract

We report on the relation between physics students and computers in developing countries. Our goal is to figure out the possibility of applying e-learning and computer modeling in the field of physics in these countries. More than a hundred Sudanese physics students, from more than ten institutes, and from various levels of education were questioned about their computer knowledge, and the availability of computers in their institutes, and whether they use computer programs in their study. Data recorded, analyzed, and interpreted due to that.

We conclude that, although most of students showed poor relation with computers and poor computer skills, it is still possible to achieve e-learning and computer modeling in developing countries institutes if some recommendations were taken into account.

Introduction

Computer knowledge is essential for any physicist in many areas of applications both theoretical and experimental. In physics education computer skills may help students to best understand the concepts, experiments, and data acquisition.

In developing countries e-learning is expected to play positive role in the enhancement of physics teaching and learning, because it allows the use of programming, internet and other computer facilities, with low cost and ease of use. This needs that students and teachers in theses countries improve their computer skills and build good relation with computers. Here we present the status of the relation between the physics students and computers in developing countries from different sides of view. A case study from Sudan is shown as a good example for our study.

Method

More than a hundred physics students from twelve different institutes were randomly selected. Students ranged from the first year up to the final year. Questions included the level of computer knowledge, hours per week spent in front of the computer, programming languages they know, and their use of computer simulations into physics problems and data acquisition. Data were then analyzed using computer software Microcal ORIGIN.

Results and data analysis

It came out from our results that 52% of the students know about computer operation in the pre-university level, while the rest (48%) start to learn about computers after they come to the university. 55% know about DOS, while the majority (86%) know how to deal with WINDOS, and only 04% have some idea about Linux. On the other hand the number of the students who know some programming languages is below 50%. Figure (1) presents students knowledge of some selected computer programming languages like Fortran, C- language, C++, and JAVA.



Fig (1): Knowledge of some computer programming languages

It also came out that only 16% of the students use computer simulations for their physics problems solving. The same is for the experimental data processing (i.e. 84% treat their experimental data manually) although results presented in figure (2) show that there is some knowledge about computer software which could be used for data acquisition and simple modeling.



Fig (2): Knowledge of students to some mathematical Software

From our study most students (96%) believe that computer methods facilitate physics learning. One important factor that influences the relation between students and computers is the accessibility to computers. Our results showed that 47.2% of the surveyed institutes have supporting computer laboratories to help students in their work. 91% of the students spend

less than five hours per week in front of the computer, 3.9% spend between 5-to-10 hours, and 5.1% spend more than ten hours a week.

Conclusion

Most of the students showed positive response to e-learning , and linking of computers to physics studying.

It is not possible to start computer modeling in physics teaching at school. At the university level intensive computer courses are essential in the first and intermediate years as a pre-requisite for the application of modeling in physics class in developing countries.

Various Physics

Playing With Gravity, Einstein's Happiest Idea

By Max Bazovsky

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Abstract

The outlined lesson plan shows (A) some general and specific steps that Albert Einstein used to hypothesize, formulate and construct one of his famous models (the gravitational redshift), and (B) the way the model was verified using the Mossbauer effect. Both parts make use of the Doppler effect as prior knowledge. Einstein's famous free-fall thought experiment is discussed, and explained using analogous demonstrations that involve minds-on and hands-on Project Based Learning (PBL). It is hoped that this contribution can lead to a Cognitive Laboratory of Operational Experiments (CLOE) on gravity for older children, to introduce them to modern research, and provide a key example for the use of meta-cognition meta-models to help develop creative relationships with models and modeling. PBL is used to help introduce the students to the Mossbauer effect.

1 The Doppler Effect in Developing the Gravitational Redshift Prediction

While playing with the idea of gravity, by means of thought experiments, Einstein (Nobel laureate 1921) constructed an amazing model that predicts the gravitational redshift, i.e., that light changes its frequency when it propagates against gravitational field. The process or method used is an example of how model construction is guided by general ideas, meta-cognition, or meta-models of reality. It takes several distinct, steps discussed below. First, Einstein did some thought experiments that might model gravity. This lead to his "happiest idea", "In free-fall, a person cannot feel their own weight".

<u>TeamWork Project 1</u> The CLOE on gravity[1,2] provides a wealth of insights as well as of references about gravity conceptions of students aged 6 to 10. It might benefit older students, especially if they happen to be challenged about gravity and need more demonstrations and discussions that show the free-fall idea both in the physics classroom and outside it. E.g., pierce a plastic bottle with a small hole near the bottom, fill it with water, and let the bottle drop in free-fall. While in free-fall, the water does not leak out. Many easy variations on this experiment exist. Design some free-fall experiments using the idea suggested by the above example. E.g., use a rubber band or a magnet which barely fails to hold up a weight while stationary. Sketch the idea and materials that you need and get the teacher's approval to proceed. They all make use of the fact that the internal stress and strain forces in a small freely falling object cannot include any significantly strong forces due to the pull of gravity. Is every satelite, like the moon or the International Space Station, ISS, in continuous free-fall?

<u>Extra credit</u>, Choose one or both of the following: (A) using the WEB for "starters", design a 3 or 4 meter high free-fall tower with a movie camera to record the phenomena. Do experiments. (B)Ask the management of a tall modern building for permission for your school group to use the elevator to perform a fun experiment to model the acceleration of an elevator as it moves from floor to floor by using a portable weight scale to obtain intereresting graphs. How does the elevator's acceleration and speed affect the graphs? How does swinging pendulum behave in the elevator/ in free-fall?

<u>Team Work Project 2:</u> Still being at the very early stages of exploring space, we are doing varied microgravitational experiments in many contexts such as in the International Space Station (ISS), (which is in continuous free-fall), in free-fall towers (where objects are dropt long distances in vacuum and studied), and various "vomit comets" (These are structurally beefed-up airplanes that can safely negotiate very high altitude parabolic trajectories where free-fall is experienced for a few seconds). Perform a WEB quest [4] to describe microgravity/free-fall experiments and facilities. What sort of phenomena will change in low gravity? E.g., how does a flame look without convection currents?

<u>Extra Credit</u> Do a WEB quest to search for gravitational waves and observatories, (LIGO and LISA). They are not directional . Why? How can we use triangulation from separate observatories to calculate their direction? LISA, is the 5 million km long space-based gravitational wave observatory currently being planned for operation in ten years time. Why must they be so sensitive to detect the waves? Why is the Doppler effect used to make corrections for the Earth's daily and yearly motions?

After his happiest idea about free-fall, Einstein asked many questions, such as, *How can I use this? What does this imply? How can I explain this fully?*, He formulated what is now known as the *Einstein equivalence principle*,

"At a "very small" local level¹⁸ one cannot tell the difference between forces due acceleration F = ma, or to a gravity field, F = mg by any mechanical or electromagnetic experiment."

See [3] for more details. This key principle guided his model construction. E.g., one of his answers to *"So what? What next?"* was the prediction of the gravitational redshift by placing two major ideas (the Einstein equivalence principle and the Doppler effect) in juxtaposition. The step by step thinking/modeling probably occured as follows:-

a. Given prior knowledge: When moving away from a light source, experimental evidence shows that the observed frequency is down-shifted (redshifted) according to the Doppler effect equations, just like the sound of a receding ambulance is down-shifted more if the ambulance is traveling faster away from the observer. I.e., the larger the velocity, the more the redshift.

b. Hence, by the principle of equivalence, when light travels up (down) a gravitational potential well its frequency and energy decrease (increase) in proportion to the steepness of the walls

This major conclusion still appears as a little startling, but Einstein boldly continued the steps. He constructed a theoretical quantitative model that predicts exactly what this gravitational redshift is. The next step was to verify that the predictions made by the thought experiment are indeed the case.

2 Using Doppler And Mossbauer Effects to Verify Gravitational Redshift Model

Einstein's predictive model was verified using the Doppler effect experimentaly in 1959 [5] within a 22.6 meter tower on the campus of Harvard University by using the then brand new technique of Mossbauer (Nobel laureate 1961) spectroscopy. Atoms of the Iron Fe 57 isotope were placed into a crystal fixture and used to radiate 14.4keV Gamma ray photons that were directed from the bottom of the tower to the top of the tower. The gamma rays were not absorbed by an identical crystal fixture at the top of the tower because they were redshifted as predicted by Einstein. The Doppler effect and the Mossbauser effect were used to show that the amount of redshift was equal within ten % (now one %) of that quatitatively predicted. The Doppler shift can be caused by wiggling either the receiving or the transmitting crystal by a precisely controled motor to very precisely measure and control the velocity of the fixture of the crystal E.g., if the receiving crystal is wiggled, then when the velocity is just right in the downward direction, the Doppler effect ensures that a blueshift occurs "for the detector", the "lost" frequency and energy are regained in the detecting process, and the photon is absorbed by the detecting crystal. Conversely, if the source is wiggled and moving upward, the blueshifted photon loses the additional energy as it travels upward. I.e., at just the right velocity as predicted, the gamma rays are absorbed. See [5] for more details. Note: Rudolf L Mossbauer (Nobel laureate 1957) discovered a method for obtaining photons from a crystal with a very narrow frequency band [6,7] by quantum transitions of atomic nuclei. Very tight precision is needed because in the 22.5 meter journey, the frequency changes very slightly. So the original frequency must be known within even tighter limits.

<u>Team Work Project 3</u> Design and build (or otherwise obtain) a wooden cart with a spring powered ball-bearing gun mounted on it. Obtain a set of weights to place on the cart and do experiments varying the amount of weight on the cart. Measure the recoil force and velocities. As more weight is placed on the cart, the less it recoils. Explain why this is so. How does this relate to the Mossbauer effect?

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¹⁸ I.e., in a very small (infinitesimal) neighborhood around the sensing equipment. Also, a large enough body can be subject to variations of the gravitational field strength of a strongly varying field. This difference in effects provides an opportunity to measure a distinct difference between gravity and "pure" constant acceleration in a flat space.

An Initial Biomedical Physics Elements-of-Competence Inventory for First Cycle Nursing Educational Programmes in Europe

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Abstract

This paper presents an initial version of a biomedical physics elements-ofcompetence inventory for first cycle nursing educational programmes in Europe and describes the process used in its development. EU legislation and documentation, standards of proficiency promulgated by professional councils, educational benchmark statements published by higher education quality assurance agencies and articles in the healthcare, healthcare professional and higher education literature relevant to standards of nursing practice, role development and undergraduate nursing education were analyzed. The current outcome competence list for First Cycle nursing programmes developed by the nursing group working within the Tuning Educational Structures in Europe framework was examined. Nursing curricula across Europe were surveyed. Competences expected of a First Cycle nursing graduate that included major biomedical physics components were identified via document analysis. These competences were in turn broken down into specific elements-of-competence and those elements falling within the biomedical physics domain singled out. A structured elements-of-competence inventory was designed to serve as a practical curriculum development tool for biomedical physics educators servicing nursing programmes within Europe.

Introduction

The research reported in this paper forms part of an ongoing project the purpose of which is to put the role of the biomedical physics educator within Faculties of Health Science on a firm foundation. The results of the study have shown that a strategic mission for the role would be:

"Biomedical physics educators will make a decisive contribution to quality healthcare professional education through the pursuit of practice-oriented curriculum research, development and delivery in the physics-engineering competences necessary for the scientific, effective, safe, ethical and efficient use of biomedical devices and the supervision of student research involving such devices. We will be guided in our efforts by our values of Excellence, Respect, Professionalism, Service, Teamwork and Lifelong Learning"

Biomedical devices are underpinned by physics principles. They are crucial to modern healthcare and the subject of several EU directives - hence offering an excellent opportunity for the physics educator to consolidate and develop his role. In this context 'effective' means ensuring that the medical device attains the intended healthcare purpose for which it is being utilized. 'Safe' refers to the avoidance of unnecessary risk to patients and the total elimination or reduction to acceptable levels of risks to users, colleagues and others from physical agents associated with medical devices. 'Physical agents' refers to ionizing radiation, mechanical, electrical, acoustic, ultrasonic, magnetic, electromagnetic, high temperature, optical, ultraviolet, infrared, and laser sources of possible risk. 'Efficient' refers to the extent that purpose is achieved at minimum device use time.

A generic curriculum development model which can be used to drive curriculum development for any healthcare profession was derived from the above mission statement. Aspects of the model have already been used for the construction of elements-of-competence inventories for Diagnostic Radiography and Medicine (Caruana & Plasek, 2006, 2005). This paper applies the model for the development of a similar inventory for the nursing profession. Nursing is by far the largest of the healthcare professions yet it has been given the least attention by biomedical physics educators. Nursing is important as it has been the first regulated profession to be included in the Tuning Educational Structures in Europe framework.

Research Design

The research paradigm of this study was practitioner research, the research approach qualitative, and the philosophical perspective pragmatic. The conceptual framework guiding the study was competence-based curriculum development, the research technique document analysis. The Tuning document "Summary of Outcomes - Nursing" (Tuning Group for Nursing, 2005) which lists the competences expected of newly qualified nurses in Europe was scrutinized and the subset of nursing competences that included major biomedical device aspects singled out. Unfortunately, since the practice of nursing is very inhomogeneous across Europe the Tuning competences have been couched in broad terms and do not indicate specific devices. Therefore for further specification we surveyed EU legislation and documentation, national nursing standards of proficiency, educational benchmark statements from higher education quality assurance agencies and research articles relevant to standards of nursing practice, role development and undergraduate nursing education. We also examined European nursing undergraduate curricula. The competences were then carefully deconstructed into elements-of-competence and those elements falling within the biomedical physics learning domain inventorized.

Results

The analysis of the Nursing Tuning competences document indicated that the aim of physics teaching within nursing education would be to ensure that learners acquire the necessary physics elements-of-competence underpinning the following broad Nursing Competences all of which involve the use of medical devices:

1. Has relevant knowledge of the following and the ability to apply this knowledge to nursing practice, patient care and situations of uncertainty: Anatomy and Physiology, including basic knowledge of Histology and Medical Biology, Biophysics, Biochemistry and Radiology.

2. Able to appropriately use a range of nursing skills, medical devices, interventions/activities to provide optimum care.

3. Undertakes comprehensive and systematic assessments using the tools / frameworks appropriate to the patient / client taking into account relevant physical, social, cultural, psychological, spiritual and environmental factors.

4. Practices principles of health and safety, including moving and handling, infection control, essential first aid and emergency procedures.

5. Safely administers medicine and other therapies.

The absence of specific devices is highly evident. In fact, these vary by state, within large states and with time and have to be ascertained at the moment of curriculum delivery on a local basis. However, the documentation analysis indicates that at present the devices to be specifically included in undergraduate nursing are those used in vital signs assessment and delivery of medication (Boxer & Kluge, 2000). Vital signs assessment devices include thermometers (mercury, electronic, tympanic), blood pressure measurement devices (stethoscope, sphygmomanometer, electronic) and increasingly pulse oxymeters. Medication delivery devices include needles, syringes and needleless systems, piggyback, volume-control, and intra-venous infusion systems, and nebulizers (Pfeil, 2001). Learning about

medical imaging devices is also required. Although nurses are not authorized users of such devices, present nursing role developments (e.g., nurse practitioner role) indicate emergent learning needs in this area. Patient safety and occupational safety for all healthcare professionals are legal requirements which are still not being given due importance in nursing curricula (Ramsay et al., 2006; Wakefield et al., 2005). Learning regarding safety vis-à-vis *physical* agents should be included as it is required by several EU directives.

The suggested biomedical physics elements-of-competence inventory for nursing is shown in the Table. The inventory would guide educators in preparing students for use of the devices they would be meeting in their undergraduate practice and also lay the foundations for the learning of those devices they would need to use after their graduation. We intentionally avoided making the inventory too prescriptive; this prevents educator and student disempowerment with respect to content, allow for diversity, and permit the development of native solutions to local curricular targets. The suggested order of delivery might need to be modified to reflect local curricular structure.

Conclusion and implications

The deconstruction of broad professional competences into elements-of-competence and the construction of discipline-based inventories are essential in the systematic development of competence-based curricula. An important use of such inventories is that of a checklist to ensure that all essential disciplinary elements-of-competence embedded within broad professional competences are included in the curriculum and that all are eventually assessed. It has long been acknowledged that nurses' understanding of the physical science component of the knowledge underpinning nursing competences is inadequate (Wilkes & Batts, 1996). This paper is a first attempt to resolve this long-standing issue.

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Europe	
Define a medical device as described in the Medical Device Directives	
Appreciate the range and importance of biomedical devices used in the clinical and resea	rch
contexts.	~1-)
Demonstrate awareness of the importance of a risk assessment (patient, occupational, public ri	SK)
with respect to physical agents before utilization of a device. Physical agents include ioniz	ing
radiation, mechanical, electrical, acoustic, ultrasonic, magnetic, electromagnetic, nigh temperatur	es,
optical, ultraviolet, initiated, laser. EU medical device fisk classes.	
signal processing modules, output devices, basic <i>qualitative</i> frequency analysis, signal digitizati bit-depth). Utilize measurement concepts (e.g., accuracy, noise, uncertainty, precision, calibrative and data processing (use of formulas for uncertainty in the mean of a set of data, linear regress and correlation coefficients) in the collection and analysis of data from physiological a biomedical laboratory measurement devices. Explain ways of reducing risk when using su	on, on) on) ion and
measurement devices	
Explain anatomical and physiological imaging devices in terms of measurement of the spa	tial
distributions of physical and physiclogical properties of body tissues and their picto	rial
representation. Safety issues in biomedical imaging.	
Understand the various forms of microscopy and the advantages and disadvantages of each.	
Apply basic image processing (e.g., zooming, magnification, windowing, smoothing and sharpen	ing
filters) for increasing the diagnostic effectiveness of images.	
Understand at a basic level the physical principles underpinning biomedical devices to be found the following device groups: radiation based therapeutic devices, intensive and critical care device renal devices, surgical and pre-surgical (e.g., endoscopic) devices, prosthetic devices a biomaterials, assistive devices.	in es, und
Understand the concepts of device performance indicator and device limitation and their relations	hip
to clinical effectiveness and safety criteria.	
Appreciate the importance of following user protocols to ensure performance indicators are	not
impacted negatively, to reduce effects of limitations of the device and to eliminate or reduce risk all concerned	to:
Demonstrate awareness that a device needs to be quality controlled for ongoing effective and s use. In particular, a device needs to be checked before use (daily QC), cared for during use and in a condition for subsequent use by self or others.	afe left
Understand how to get maximum benefit from reading the user manual of a device.	
Explain ethical issues in the use of devices (e.g., qualitative risk-benefit analysis, equitable use resources, the importance of the economical use of devices, the obligation to optimize benefit a minimize risk).	of Ind
Explain EU Directives regarding medical devices and patient and user safety.	
Appreciate the variety and potential far-reaching effects on clinical medicine of emerging dev technologies (e.g., telemetry, automation, robotics, point-of-care (POC) devices, micro and na devices molecular imaging virtual reality systems)	ice no-
Apply the above competences to the effective safe ethical and efficient use of the spec	ific
biomedical devices used in their clinical practice (the specific devices varies by state, within la	rge
states and with time and has to be ascertained at the moment of curriculum delivery on a lo basis).	cal
Appreciate the need for patient radiation protection as required by the role of nurse prescriber.	
Demonstrate a scientific attitude in the use of devices in biomedical research.	
Note: Please address feedback regarding the above inventory to Carmel J. Caruana (carmel.j.caruana@um.edu.mt). Suggest	ions

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What is "particle" or "space" a metaphor for? Students facing the complexity of modern physics

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Abstract

The paper illustrates results of a research project concerning an "educational reconstruction" of modern physics (relativity and quantum physics).

The research aims at re-shaping the current debates on Foundations, Philosophy and History of Physics in order to design intelligible and practicable routes along which secondary school students can be guided to face the following questions: What are space and time in current research in physics? How does the concept of "object" change from classical to modern physics?

The discussion will focus on identifying to what extent guiding students to recognise "space" and "particle" as *models* implies facing the complexity of physics thinking. Accepting complexity as an intrinsic feature of physics thinking led us to find out criteria for designing teaching paths in which complexity, instead of being removed, was re-organized so as to become manageable by the students.

Preliminary results of classroom implementations with 18-19 years old students will be presented.

"Logical coherence is a purely negative criterion; no system can be accepted without it, but no system is acceptable just because it is logically tenable". (Max Born)

Introduction

The aim of the research project we are carrying out is designing materials for teaching modern physics (relativity and quantum mechanics) at the High School level. One specific concern is addressing some problems come of the *oversimplification* of traditional teaching.

A look at secondary textbooks and popular science books suggests that, moving from classical to modern physics, reasoning and arguments tend to become less and less articulated, ending with nuclear physics presented as pure nomenclature: a collection of notions that students learn by heart and easily forget lacking the necessary cognitive tools to turn information into Culture (Grimellini Tomasini, 2004).

Moreover the local oversimplification of contents leads to some *global inconsistencies*, such as:

- special relativity is usually presented as the theory which overthrew Newtonian absolute concepts (among which is the idea of absolute space and time as real, substantial containers), whereas general relativity is usually popularised with images of a spacetime *container* so real to be curved by matter (fig.1). This kind of pictures as well as suggesting the wrong idea that what is curved is space (instead of spacetime) strongly enforces the idea that the space container, refused by special relativity as a "monstrous conception", as Mach said, re-appears in general relativity;
- in learning quantum mechanics students are supposed to be convinced that the classical image of microscopic object as a particle is irreversibly destroyed by the wave-particle dualism, the uncertainty principle and entanglement. Nevertheless, students who leaf through the textbook find a chapter entitled *elementary particles*, often illustrated with pictures like the one shown in fig.2.



Figure 1 - Spacetime in General Relativity



Figure 2 - The microscopic world (Greene, "The fabric of cosmos", 2004)

Inconsistencies arise since students, unlike physicists, have no other chance than reading the images literally.

The point is: Is it possible to enable students to understand such images in a meaningful way? And, mainly, what is nowadays *space* or *particle* a metaphor for?

Even a quick glance at the current debates in physics and on Foundations, History and Philosophy of Physics shows that what appear to be inconsistencies in teaching of modern physics are real crucial problematic issues upon which no univocal position exists among physicists (admitting that an univocal position is possible and desirable).

In other words, the search for answers to primitive questions (like *what are space, time, photons?*) requires to *extract* the educational potential of highly specialized debates that, although respecting the same formal and experimental constraints, appear as a tangle of different interpretations sometimes leading to apparently inconsistent, if not conflicting, conclusions.

From an educational perspective the analysis of the debates opens serious problems: how to face the complexity of physics? To what extent can complexity be reduced without loosing any constitutive feature?

Complexity of Physics and Physics Education

Within research in Physics Education it is quite easy to recognize different ways of looking at and facing the complexity of physics. "On one hand, complexity is considered as maybe the main demotivational factor that, consequently, must be reduced as much as possible. On the other hand complexity is considered as a feature of thinking and, as such, not to be removed but organized in order to make it as manageable as possible." (Levrini & Hammer, 2006)

Accepting complexity as a matter of fact implies to re-define some basic research questions. In particular it requires to outline what diSessa calls a "profile of complexity" (2006): a balance between *complexification* and *intelligibility* which has the potential of avoiding both to trivialize physics and "loose" students. In the paper we will report some results we consider as crucial points to be taken into account in outlining such a profile.

Re-constructing modern physics

The *educational reconstruction* we are presently involved in aims at designing paths addressing the following questions: What contributions did special and general relativity provide to the debate about the nature of space and time? How does the concept of "object" change from classical to quantum physics?

The general criteria identified for respecting both the complexity of physics and the intelligibility of the paths are:

- instead of a discipline whose unique goal is providing answers, physics is presented mainly as the *art of posing questions* and the paths are developed as progressive reformulation of basic questions as knowledge construction advances;
- instead of a neutral conceptual development of the contents, the "objective core" of the theory is situated within an *interpretative framework*, by presenting at least two different interpretations, emphasizing their inner coherence, their historical roots and the particular world view or epistemological option their represent;
- the *core concepts*, emphasized by the research in physics education as crucial for understanding, are addressed several times along the different interpretative lines and discussed both for their "pure" physical meaning and for the role they play within each interpretation.

In the following sections some results from implementations with 18-19 year-old students attending the last year of Liceo Scientifico (a science-oriented high school) are reported.

Some results from classroom implementation

1. Complexity for enlarging the argumentative repertoire

The main result of the re-construction of spacetime physics is the discovery of the educational potential of the historical and still open debate between substantivalism and relationalism, that is between physicists/philosophers who maintain that space and time are substantial containers (like Newton) and those who consider space and time as human mind constructions (like Leibniz).

An educational re-construction of the debate allows the aforementioned inconsistency to be solved, by providing arguments for supporting that both special and general relativity admit different interpretations, with or without assuming spacetime containers.

In particular, even though special relativity is usually taught as the theory which allowed space and time containers to be removed from physics, according to Einstein's interpretation, it is also possible to argue that, as Minkowski did, the main contribution of SR is not removing the two Newtonian containers but unifying them into a unique spacetime container (Levrini, 2002).

From an educational point of view, the debate allowed students to enlarge the argumentative repertoire for analysing the core concepts (like the concept of event, "frame of reference/observer", proper time and proper length, relativistic effects), limiting the risk of mental short circuits students tend to do in order to preserve the classical idea of space and time as two separate "real" properties of an object or a phenomenon (Posner et al., 1982; Levrini, 2004).

2. Complexity for getting involved and accepting the quantum formalism

At present we are particularly engaged in re-constructing quantum physics for educational purposes. The path has been implemented in three regular instruction classes at the Liceo "A.Einstein", in Rimini. The teacher is one of the author (PF) and has taken part in the research project since the beginning.

The path, besides stressing the progressive falling down of the properties classically attached to the object, aims at enabling students to cope with the Pauli's matrix formalism for spin (Pospiech, 2004).

The first part of the path concerns the analysis of the following historical debates between:

- Heisenberg and Bohr about the interpretation of uncertainty;
- Bohr and Einstein about determinism and the relationship between knowledge and reality;
- Heisenberg and Schrödinger about the visualization of quantum objects.

The aim is to show how dramatic has been giving up the classical image of the world (Tarsitani, 1983) and to pave the way for the second part concerning quantum formalism. The debates play also the role of creating in the students the necessary knowledge tension to see the formalism as an help for re-organising in a solid structure many concepts previously introduced, like the concepts of *quantum system, state, non-epistemic probability, superposition principle, measure process, uncertainty.*

In the following section we will report some students' reactions taken from an open questionnaire submitted at the end of the instructional period. The quotations chosen appear particularly meaningful for problematizing the role of complexity: "The 'simple and unproblematic' is intuitively also boring and lifeless in the same way that the zeitgeist of simplicity recognizes that complexity often burdens" (diSessa, 2006).

Students' reactions

About arriving at the formalism through a progressive re-formulation of unanswered questions:

• *for understanding*

"The opportunity of "hearing" the theories of the most important physicists of that time, like Bohr or Heisenberg, has been fundamental. Only through a comparison among contrasting positions is it possible to arrive at the core of the question under consideration." (Marco)

• for creating a knowledge tension

"I enjoyed seeing the different perspectives. One realizes that physics is not only a set of barren formulas, not only the uniform rectilinear motion. [...] One has not only the results, but can follow the ideas development. This "narrative" aspect makes the path more interesting... it is like reading a romance and you want to know what comes in the end." (Andrea B.)

• *for turning learning difficulties into cultural challenges* "The proposed path has been very stimulating, since, because of its difficulty, it forced my mind into a continuous comprehension effort." (Marco)

"It has been hard, but it was a challenge. If I concentrate on assessment, I prefer an approach with more exercises. If I concentrate on my life also out of the school, I prefer such a path." (Andrea R.)

• for shifting learning difficulties from intelligibility to acceptability "The problem was not understanding but accepting the consequences of the theory." (Michele)

"I found the path very stimulating and interesting (really!); easy ONLY from a technical point of view (calculation, exercises), since the theoretical part requires a lot of reflection and, I think, personal interpretation." (Francesco)

"[formalism] was not a complication, since formalism has been easy to memorize and understand, but, I mean, clear only internally [...] Quantum mechanics is upsetting since it requires to face the knowledge problem, it makes you ask if what we observe is really what it is." (Simone)

We consider the last evidence particularly relevant since students show that they are consciously going through the different dimensions that comprehension requires: relevance

and fruitfulness are indeed necessary conditions for transforming intelligible contents into real culture (Posner et al., 1982).

Triggering such a refined knowledge process, the path opens a somehow offbeat problem: how to satisfy the high cultural students requests?

Conclusions

The aim of solving some inconsistencies existent in the global development of physics content knowledge implies to face directly the complexity of physics thinking. The choice we made of accepting complexity as a matter of fact led us to find out criteria for designing teaching paths in which complexity was not eliminated but re-organized so as to become manageable by the students. The results of experimentations problematize the idea that complexity burdens, as well as the idea that the interpretative problematic dimension of physics is, at the best, a sort of luxury. Such results represent the basis for outlining a "profile of complexity".

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Learning Particle Physics at CERN or The "HST05" evaluated

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Abstract

Since 1978 CERN has been promoting programmes for High School Teachers (HST). From the 3rd to the 23rd July 2005, there were 32 of us coming from 20 different countries. We had different ages, looks and speech. The 3rd we were unknown to each other and on the 23rd we were the "HST05 team".

How can 32 wise people turn into a group of happy, somewhat foolish, Physics Teachers?

Welcome all in a get together party with refreshments, snacks and smiles. Tell them they are important to introduce students to Scientific Research and to emphasize the beauty of Particle Physics. Join them in class rooms and teach lessons about:

- ✓ Historical evolution of Particle Physics;
- ✓ Cosmos from a Particle Physicist point of view;
- ✓ Detectors, colliders and their technologies;
- ✓ Matter and anti-matter;
- ✓ Feynman diagrams;
- ✓ The goals of the Large Hadron Collider (LHC);
- ✓ The Top Ten Mysteries of the Universe.

Don't forget to tell that they sit in chairs once occupied by Nobel Prize winners. To get really special feelings, let them have a lesson given by one of those Nobel Prizes: Jack Steinberger will tell about his life and work and how happy are those who work in Physics Research.

- It's important to add social activities like:
 - ✓ *pic-nicks*;✓ meals with
 - \checkmark meals with international gastronomy;
 - ✓ firemen ball;
 ✓ Geneva treas
 - ✓ Geneva treasure hunt;
 - ✓ *barbecue* with salads and songs.

Wrap all with warm feelings and you will turn each participant into an enthusiastic ambassador of Teaching Modern Physics in High Schools.

Introduction

Our selection to participate in the High School Teachers' Programme that took place during July 2005, the "HST05" course, was received with great enthusiasm. We knew CERN as an excellent Institution of Particle Physics Research and had some notion about how people, coming from the "whole wide world", were welcomed there. We aimed to learn about the last developments in Physics knowledge and, with some luck, to get acquainted to those who build them.

Being Teachers of Physics, we had some theoretical information obtained during our University studies and many years of school teaching practice. We hoped this information would be enough to cope with the demands of the programme.

Our expectations were widely exceeded.

Theoretical Background

When an educational event is dedicated to Teachers, it is only natural that they observe and collaborate according to their own teaching practice. Usually we acquire new concepts using those we already possess (Ausubel, 1978). In fact, we were asked to

tell what we wanted to learn, during "HST05" course, before it begun. Our expectations were: to learn about Modern Physics which can no longer be left out of the High School Physics syllabus

(Hobson, 1995), to think about new ways of teaching and to know colleagues and experiences from other countries.

The way we were received, during "HST05", reminded us that to succeed, an educational event like this course should address not only the reasoning of the learners, but the way they feel and act (Novak, 1998).Our feelings and actions begun expressing themselves from day one when, near the Microcosms exhibition, we got together around some snacks and refreshments. It was our first opportunity to know each other, to show our skills in speaking English and to express ourselves in different languages (sometimes even our own).

From day one it was clear that our hosts were not only ready to share some of their knowledge but were also interested in knowing about us, the way we thought, felt and acted. However, it was necessary to attend the whole programme to realize how important the social environment was to promote effective learning and sharing of experiences (Vygotsky as quoted in Moreira 1999).

Our Hosts at CERN

Our hosts at CERN were all Physics Researchers who dedicated much of their time organizing a programme addressed to us, High School Teachers. They say they do it because it's expected that by 2015 there will be a shortage of 700.000 scientists/engineers in Europe and as teachers we could act as a link between students and Physics related professional choices.

However this doesn't explain all that happened during the following three weeks. Smiling all the time, they gave us Physics lessons, inquired about our doubts and encouraged us to ask questions. Then they explained again, when necessary.

We also had guided visits to accelerators and detectors where other scientists or engineers explained the theoretical and practical foundations of huge machines. And they did it with such enthusiasm that they looked like little children telling about their favourite toy. In return they only asked us to make our students feel how important it is to study Physics.

The Contents of Learning

We learned so many new things that we will have a lot to study in the near future. In some cases we reorganized pre-existent knowledge but, in other cases, we were surprised by extraordinary news. The content of our lessons was already listed in the introduction.

The LHC (Large Hadron Collider) is, nowadays, the shining star of CERN. It will be the biggest collider ever built and it's being assembled in a pre-existent circular tunnel (the old LEP) with a perimeter of 27 Km and placed 100 m deep. They expect it will begin working during the year 2007 and they intend to use it to:

- ✓ Discover the crucial missing element of the Standard Model, namely the Higgs boson;
- ✓ Search for possible new fundamental interactions, too weak to have been observed so far;
- ✓ Search for possible new generations of quarks and leptons;
- ✓ Confirm/disapprove the elementary nature of quarks/leptons;
- ✓ Discover direct evidence for the particle responsible for the dark matter in the Universe;
- ✓ Collect further evidence for a grand unification of the fundamental interactions at a scale of 10^{15} GeV.

We also learned that dark matter and dark energy are no fiction at all: it's believed they constitute 95% of the Universe. This showed us that we know very little about Physics yet.

The Social Programme

Side by side with hard work we had always lots of fun. We didn't need formal suits/dresses and we had no "paparazzi" chasing us but we enjoyed the social activities listed in the introduction. All of these were documented through photographs and pictures/films in our own memories.

A Very Special Gift

On Wednesday, the 20th July, we received a very special gift: a lesson given by a Nobel Prize winner, Jack Steinberger. Looking like the experienced and wise Professor that we all would like to become, he told us about his work and life. From his speech it was clear how our choices in life depend on what is happening around. And he told us how lucky he was for having been one of Fermi's students. He described the experience that gave him the Nobel Prize emphasizing the team work it required instead of his own.

We asked him what advice could be given to today's young people in order to make them choose professional carriers related to Physics, but he didn't like this question. We shouldn't have asked it, he said. How appealing can Physics Studies be to people that are starting families when they can expect but *post-docs* during the best part of their productive life? How to tell them to work on experiments whose results take around 15 years to come out when, eventually, they are already working somewhere else? Suddenly he acted like having an insight and said he just remembered a good reason: **Physics makes people happy, he never knew a Physicist who was professionally unhappy.**

The class ended with many pictures where all of us are smiling around a very patient Jack Steinberger.

Evaluation

We evaluated the "HST05" course with the highest mark on any scale. For a better organization of the information we would like to pass on, we decided to elaborate a V diagram (Gowin, 1981) where we try to ask the leading question: **How important are HST programmes at CERN?** (Figure 1).

According to the Theory of Education by Novak (1998) we separated the contents of our evaluation into the three components of human activities: **Thinking**, **Feeling** and **Acting**.

On the left side of the V diagram we enumerate the main theories we recorded, on the right side we relate the essentials of what we have done and how we evaluate it and, on the central part, we state the way we felt about it all.

Acknowledgements

I would like to thank CERN for allowing me to participate in "HST05" programme. And in the person of Mick Storr, my special thanks to all those who made us so welcomed during three weeks in CERN. They turn "HST05" into an unforgettable experience.

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Brownian Motion in Viscous Liguids; Model and Numerical Simulation

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Abstract

We propose a model of Brownian motion of sphere particles in viscous liquids. The model can be solved analytically and simulated numerically. The analytic solution leads to the known diffusion law $\langle r^2 \rangle = Dt$ where the diffusion constant D is expressed by the radius and the mass of particles, the viscosity of liquid and the average time between consecutive collisions of the observed particle with molecules in liquid. The latter allows to make a simulation of the Perrin experiment and verify how the number of observed particles and the length of observation time influences the expected theoretical results. With the help of the analytic solution and presented numerical simulation we argue that the statistics usually used in real experiments is too small to achieve reasonable results being in agreement with the diffusion theory. To avoid the problem of the small statistics causing departures from the diffusion law we introduce the idea of so called Artificially Increased Statistics (AIS) and prove that with this method of analysing experimental data one can confirm the diffusion law even following trajectories of just few particles immersed in the liquid.

II. Introduction

Recently a big progress has been made in application of digital techniques in experimental physics what allows even students to perform milestone physics experiments at their own university laboratories. A good example is the Perrin experiment [1] – the first one that directly proved the atomic structure of matter. This experiment can be verified in student laboratory [2, 3, 4], however in some approaches [2, 4] it is difficult to confirm the linear dependence between the average squared displacement $\langle r^2 \rangle$ of the particle in media and the observation time t as required by the Einstein – Smoluchowski diffusion law [5].

It is essential therefore to examine the minimal statistics (number of particles) one should consider in the limited observation time to reveal the major features of the diffusion law.

We propose an analytic Brownian motion model which can also be easy simulated numerically. The aim of this model is to investigate how the results of $\langle r^2 \rangle$ versus t depend on the number of observed particles and observation time. This study should help to set up the experiment properly and correctly analyse obtained results.

II. Description of the Model

Let the trajectory of a given mezoscopic particle of mass m in 2-dimensional space is $x^{\alpha}(t)$, where $\alpha = 1, 2$. We assume $x^{\alpha}(t)$ to be the discrete 2- dimensional time series with constant spacing τ in time, i.e.: $t = 0, \tau, 2\tau, ..., N\tau$.

The obvious notation $x^{\alpha}(i\tau) = x^{\alpha}_{i}$, $i \in N$ and $\Delta x^{\alpha}_{i} = x^{\alpha}_{i+1} - x^{\alpha}_{i}$ will be applied, where Δx^{α}_{i} is the instantaneous displacement of particle at $t = i\tau$.

The physical meaning of τ is the average time between consecutive collisions of the mezoscopic particle with other molecules in media. We assume that motion is stationary with no drift $\langle \Delta x^{\alpha} \rangle_{n} = 0$, and no correlations between different displacements. Hence:

(1)

$$\Delta x^{\alpha}_{i} \cdot \Delta x^{\alpha}_{j} >_{n} = \delta_{ij} \sigma^{2}$$

where $\langle \cdot \rangle$ is the average taken over the ensemble of *n* mezoscopic particles.

The total mean squared displacement $\langle \Delta r^2 \rangle_n$ of the particles from their initial positions after N collisions can be easy calculated with the help of (1):

$$\left\langle \Delta r^2 \right\rangle_n = \left\langle \sum_{\alpha=1}^2 \left(\sum_{i=1}^N \Delta x_i^\alpha \right)^2 \right\rangle_n = \sum_{\alpha=1}^2 \sum_{i,j=1}^N \left\langle \Delta x_i^\alpha \Delta x_j^\alpha \right\rangle = \frac{2\sigma^2}{\tau} t$$
(2)

In order to calculate σ^2 let us notice that

$$\Delta x^{\alpha}_{i} = \tau < v^{\alpha}_{i} >_{\tau}$$
(3)

where $\langle v_i^{\alpha} \rangle_{\tau}$ is the time average velocity of the particle between *i* and *i* + 1 collisions. Hence, from eqs.(2) and (3):

$$\sigma^{2} = \tau^{2} \left\langle \left\langle \nu_{i}^{\alpha} \right\rangle_{\tau}^{2} \right\rangle_{n}$$
⁽⁴⁾

From the principle of equipartition of energy:

$$\frac{1}{2}m\left\langle\left\langle \nu_{i}^{\alpha}\right\rangle _{\tau}^{2}\right\rangle _{n}=\frac{1}{2}kT,$$
(5)

where T is absolute temperature and k is the Boltzmann constant. Therefore eq. (2) reads

$$\left\langle \Delta r^2 \right\rangle_n = \left(\frac{2kT}{m}\tau\right) t \tag{6}$$

The formula above is the standard diffusion law with the diffusion constant

$$D = \frac{2kT}{m}\tau\tag{7}$$

expressed in terms of τ .

Usually one expresses D in terms of media viscosity η as

$$D = \frac{2dkT}{\alpha} \tag{8}$$

with d = 2 (for 2-dimensional space) and $\alpha = 6\pi r \eta$ (Stokes law), where r is the radius of considered sphere particles. Therefore, from eq. (7) and (8)

$$\tau = \frac{2m}{\alpha} \tag{9}$$

In the case of latex spheres with radius $r \sim 10^{-6}$ m immersed in water with $\eta_w = 1.00 \cdot 10^{-3}$ Pa·s (20°C) we find $\tau \sim 10^{-7}$ s.

Thus the presented model

- iii) correctly reproduces the known diffusion law,
- iv) gives the estimation of time τ between consecutive collisions in the system as the simple function of macroscopically measured quantities (e.g. temperature and diffusion constant).

The relation in eq. (6) can be checked via numerical simulation of the Brownian motion in media with different viscosities. In this the way one can find the sufficient number of particles in the ensemble we should observe in real experiment to obtain reasonable results, i.e. results being in agreement with diffusion law. If the number of investigated particles is too low one observes significant departures from the linear behaviour $\langle r^2 \rangle$ vs time [4] what may frustrate students in lab as they basically find from the experiments that the linear dependence in diffusion law is very suspicious.

Therefore we simulated the time series $\{\Delta x^{\alpha}_{i}\}$ in the iterative way:

$$x^{\alpha}_{i+1} = x^{\alpha}_{i} + \Delta x^{\alpha}_{i}$$

(10)

where Δx^{α}_{i} are generated as the random gaussian numbers $\mathcal{M}(0, \sigma)$ with the standard deviation σ obtained from eqs. (4) and (5) as

$$\sigma = \tau \left(\frac{kT}{m}\right)^{\frac{1}{2}} \tag{11}$$

To avoid enormous number of steps in computer modelling (in the case of water the number of steps $N = t/\tau \sim 10^7$ per second) all simulations were performed for viscosity of an artificial medium $\eta = 10^{-2} \eta_w$ changing numbers of particles from n = 10 up to n = 180. The corresponding plots $\langle r^2 \rangle$ vs t are shown in Figs 1a – 1c.

Fig. 1a. Simulated runs for n = 10.



Fig. 1b. Simulated runs for n = 60.





Each figure shows 12 randomly chosen runs with **a**) n = 10, **b**) n = 60 and **c**) n = 180 particles immersed in the liquid. Straight line represent the diffusion law (for $n \rightarrow \infty$). One recognizes that the length of observation time is not so important as the number of observed particles. For $n \sim 10$ the range of linear dependence $\langle r^2 \rangle$ versus t is difficult to determine at all. For quite short observation time as 7 s many runs don't reveal the linear dependence and even if some of them do, their slopes differ from the theoretical value up to 50%. For $n \sim 60$ the linear dependence $\langle r^2 \rangle$ versus t for most runs is revealed for t < 20 s, but a good accordance with the theoretical value of the diffusion constant within 10% one can obtain for t < 10 s. It is not surprising therefore that experimental data for n = 5 particles (Fig. 2) does not support the Einstein – Smoluchowski law, i.e the linear dependence between $\langle r^2 \rangle$ and t.

If *n* increases up to ~ 200 the range of linear dependence also increases. For n = 180 the linear relationship approaches t = 40 s (see Fig 1c.).

It is worth to notice that in student lab with the standard equipment it is virtually impossible to follow the trajectories of more than few particles in 2 hours sessions.

III. Artificially Increased Statistics

There may exist a 'Life-belt' for students who are not able to take data from more than $n \sim 10$ particles during one lab. We call it Artificially Increased Statistics (AIS). The main idea of AIS is that the statistics is built initially from the data of the one particle trajectory. Its basic rules are shown in Fig. 3. For instance: if the observation time t = 30 s and the sampling time $\Delta t = 0.3$ s then one can obtain for one particle the following increased statistics:

100 displacements	for $t = \Delta t = 0.3$ s
99 displacements	for $t = 2\Delta t = 0.6$ s
2 displacements	for $t = 99\Delta t = 29.7$ s
1 displacement	for $t = 100\Delta t = 30.0$ s

Then this statistics is averaged over all *n* considered particles. Even if *n* is small ($n \le 10$) the overall number of displacements entering statistics is large enough to fulfil the linear dependence expectation. This phenomenon is shown in Fig. 4 (data taken from the real experiment with water and glycerine). The comparison with plots in Fig 2. shows the significant improvement of the linear dependence law.

Fig. 2. Plots $\langle r^2 \rangle$ versus time averaged for 5 particles. Samples of experimental data for latex spheres of diameter of 850 nm immersed in water and water solution of glycerine (taken from [4]). Numbers in parenthesis correspond to expected theoretical values



Fig. 3. The basic idea of the AIS. The dots show a sequence positions of one particle. The blue lines represent displacements taken into account when calculating $\langle r^2 \rangle$ for $t = \Delta t$. The red lines correspond to displacements used to calculate $\langle r^2 \rangle$ for $t = 2\Delta t$ and the green ones show displacements used to calculate $\langle r^2 \rangle$ for $t = 3\Delta t$, etc.







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Diffraction of Light in a Model-Sensitive Approach in Physics Instruction

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Abstract

Diffraction of light as a common topic in school physics is attended by difficulties: Learners conceptions on models of light and of diffraction frequently are not adequate in the physical sense. A computer program on diffraction of light by a single slit was designed following the theory of learning about models and evaluated. Two variables were investigated concerning their influence on knowledge acquisition: Firstly the text surface design which refers to aspects of the linguistic structure of the text, in particular the text coherence and to the text-picture references. Secondly the instruction to self-explain was analysed for effects.

Students (N=80, grade 12) learned with the computer program and their knowledge acquisition was assessed with pre-, post- and follow-up testing on optics. Results in general show positive effects of self-explanation on learning physics in the domain of optics (p=0.009), while the characteristics of text surface do not influence the learning outcome significantly.

Analysis of data will focus on students' conceptions that become visible in items of the knowledge test. Selected protocols of self-explanation are interpreted concerning students' understanding of diffraction. The evaluation shows that though students acquire significant knowledge during the treatment, they still have difficulties in choosing adequate models of light, and applying them to new situations. Due to this learners juxtapose diffraction phenomena and shadow formation in an inadequate way. This is interpreted as a need for more extensive learning about models in physics education.

Introduction

Diffraction of light is a common topic in physics instruction in school and it often goes along with the first implementation of the wave model of light. Students are familiar with optical phenomena as refraction and reflection at this point in time and have learned to explain them with the model of light rays in geometrical optics. Now they are supposed to know both - the ray model and the wave model of light -, to realize their implications and to use them adequately. This implies that the students also know about the boundaries of each model concerning their mightiness of explanation.

However the subject of diffraction and interference of light is attended by certain difficulties: Students show difficulties in understanding the wave model of light qualitatively and in distinguishing basic assumptions of different models of light. They combine the different models of light in something that can be described as "hybrid models" or they apply one model when the other is needed (see Ambrose, Shaffer, Steinberg, & McDermott, 1999). In terms of science education the students' (mis-)conceptions in many cases differ from the scientific conceptions.

This is in line with the constructivist assumption that students have to construct their own knowledge based on their prior knowledge. This prior knowledge in the form of (mis-) conceptions is hard to change or to extinguish. It normally continues to exist in addition to scientific ideas (Duit, 2003).

In order to promote better student understanding of models of light and the nature of models themselves a model sensitive approach in the sense of "learning about models" according to Mikelskis-Seifert (see Mikelskis-Seifert & Leisner, 2004) seems promising. By explicating the features of a model in general and by paying more attention to the model character of light rays and light waves it should be easier for students to reflect on the correct use of the models for the explanation of physical phenomena.

In this paper we will present students' conceptions in wave optics that were observed in an empirical study that had two other focal points that won't be discussed here in detail: The

influence of text surface design and the impact of self-explanation in the context of learning physics with computer based multimedia (for details see Rabe, 2005).

Methods

A computer program on single slit diffraction was developed and employed in the study. Concerning technical aspects the program was designed according to the purposes of the study: Only visual text and static pictures, a linear structure, a processing time of about 50 minutes.

The content of the program is curricularly valid which makes it adaptable for school lessons. It was prepared in a way that allows to implement the program into a curriculum based on the approach of "learning about models". Limitations of the ray model of light and implications of the wave model of light are addressed while introducing the phenomena diffraction and interference of light and their explanation.

In an experimental design 80 students from grade 12 who participate in physics courses in German public schools worked with the computer program individually during one session in the presence of an instructor. The self-explanations of students were recorded and partly transcribed.

The central instrument of the experimental study was a test on knowledge in this special domain of optics that was used at three points in time, before, directly after and 6-8 weeks after the intervention (pretest, posttest, delayed posttest). The test consists of multiple choice items, items with drawing tasks, items with verbal answer format and a few mathematical items.

In the following selected items will be analyzed with regard to students conceptions and their change during the intervention.

Results

Before going into a detailed analysis of single items it has to be pointed out that students in general were to acquire knowledge of remarkable extent with the computer program. Otherwise the impression could be received that only misconceptions were observed. Figure 1 shows the results of the knowledge test for pretest, posttest and follow-up test. The mean score of the test changes obviously and results of posttest and follow up test both differ significantly from the knowledge prior to instruction.



Figure 1. Results of statistical evaluation: Scores of the knowledge test

In a multiple choice item the following question was asked (Item 5): "A diffraction pattern on a screen is generated by a vertical single slit. What can one observe if the left half of the slit is covered?" Five answers are offered to the students who are allowed to choose more than one of the alternatives:

- a) The maxima on the right side of the screen disappear.
- b) The maxima on the left side of the screen disappear
- c) The maxima move further together
- d) The maxima move further apart
- e) Nothing changes

For qualitative evaluation the answer frequencies for pre-, post- and follow up-test were counted as shown in figure 2.



Figure 2. Distribution of students' answers to Item 5

In the pretest before learning about the wave model of light and diffraction half of the students choose answer b implicating that the direct way of the light through the slit towards the screen is blocked and therefore a shadow is caused. A similar argumentation might be the reason why another 18% of the students find answer a plausible. These learners do not know or realize that an even thinner slit will continue to cause diffraction but the shape of the interference pattern changes: Concepts of diffraction phenomenon and shadow formation are mingled.

In the posttest more than 50% of the students now opt for the correct answer d, however, half of the students still select one of the distractors. In the follow up test less students remember the correct answer and the wrong answers are chosen more frequently again. This shows how difficult it is to change students' conceptions in general and that they tend to fall back into more familiar argumentations as it is the case with the ray model of light and the phenomenon of shadow.

The computer program focuses on diffraction at a single slit. In the knowledge test students are asked to sketch the interference pattern if such a slit is used (Item 4a), if a square opening (of the same dimension) is used (Item 4b) and if a circular opening (of the same dimension) is used (Item 4c). To give a correct answer students are required to make use of their transfer ability, since they have to realize that the additional boundaries of the different shapes cause extra interference of light behind the opening.

Students sketches were grouped by following methods of qualitative content analysis. The following six categories emerged:

- a) Wrong or non interpretable drawings
- b) Correct drawings
- c) Hybrid drawings
- d) Shadow pattern
- e) Construction sketch with ray model of light
- f) Construction sketch with ray model of light

An interesting group of drawings concerning students' conceptions are the hybrid sketches in category c. They show again a compound of ray model assumptions and argumentation in the wave model of light as can bee seen in examples in figure 3.

Figure 3. Student's sketches referring to Item 4b and 4c: Hybrid drawings



The student does draw an interference pattern, but it shows the structure of a pattern observed with light at a single slit. What changes is the shape of the maxima: They become square or circular as if the shape of the opening causes a different form of a shadow. The student seems to acknowledge that there has to be interference too, but fails to determine what the pattern looks like.

How much the students trust in the mightiness of the ray model of light can be seen in the sketches of category d, where a bright area on the screen is surrounded by shadow. These students do not realize that interference happens though it is even said in the task (see figure 4).

Figure 4: Student's sketches referring to Item 4a and 4c: Shadow pattern



In the case displayed here the student even explicitly comments on the drawing "a bigger slit/ a bigger circle is generated".

For the analysis of items with a verbal format it was necessary to categorize the students' answers. To illustrate the variety of students' ideas examples of the answers and their interpretation will be given. In one item of the knowledge test students are asked to explain the phenomenon that light falling on a fine grid causes an observable colored pattern on a screen behind it. Students explain this as follows:

- "Refraction of light occurs and the light is divided into its colors." The diffraction and interference phenomenon is interpreted as a result of refraction of light comparable to the spectrum of light that becomes visible after the light has traveled through a prism.
- "The colors of light have different wavelengths. If the amplitude of the waves is too large, they do not fit through the grid. Because of that only some colors pass the grid and one observes a colored pattern." The following quote is another example for this idea: "Only certain wavelength can pass." In these answers the grid functions as a filter whereas it is not clear whether the amplitude or the wavelength is the crucial factor. They might be confused as well. At least the light has a feature that can be too big of size to pass the openings of the grid
- "Rays of light can't pass some of the bars of the grid." In this answer the argumentation probably bases on the ray model of light in which the bars of the grid could block the light falling on it. Then the pattern would be understood as caused by shadow.
- "The light is split into smaller rays and by that into different wavelengths." From this quote one can guess that the ray model and wave model of light are not distinguished, because a wavelength is attributed to rays of light. But more interestingly the grid has the ability to split the rays and in this process the wavelength changes too.

Conclusion

The statistical analysis has revealed that students gained knowledge on diffraction and interference of light partly even in a sustainable way as the follow up test shows. Despite this

general success a lot of difficulties in students' understanding have been observed. Students' misconceptions in optics in many cases are due to uncertain knowledge on the features of the models of light and their confusion. Students are not aware of the model character if light is described as a ray or handled as a wave. Therefore they do not realize the limited validity of the models. If a computer program as used in this study is implemented in a curriculum that emphasizes a learning about models one could expect that students become more sensible concerning the model character of rays and waves. It could help them to stabilize their knowledge in optics so that persistent misconceptions might be overcome.

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Students' conceptions and reasoning models of the electric force and field related questions in the interviewed CSEM test

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Abstract

This study explores undergraduate students' conceptions and reasoning models of electric forces and fields. It is based on their answers and explanations given in the interviewed CSEM test questions 6 and 13. The results indicate that the students are able to apply Coulombian force only in relatively simple problems, but they fail in using appropriate electric field models in cases the Coulombian force is no longer adequate concept for modeling more complicated phenomena. These findings among with the one concerning the disability to transfer the knowledge of vector calculus to the physical context can not be overlooked in the implementation of the introductory course of electromagnetism. The instruction should be based on students' prior knowledge about forces and vectors. By introducing new tools for representing the fields the students can be helped to build themselves scientifically acceptable model of electric field. This can be done by doing certain problems where the student has to define, represent and explain the *electric field vectors* in arbitrary points in the proximity of a charge distribution both algebraical and graphically.

Introduction

In this study the students understanding of the electric force and electric field concept was studied. According to Furio [1], the students fail in changing their thinking from force concept to the theoretically superior field concept. Reasons for this are the misconceptions regarding the electric field lines and vector thinking as found by Törnkvist [2], and electric field generally as noted by Viennot [3].

Research question and method

Based on the presented remarks the following research question was formed:

How are the students able to apply the electric force and field models in case of some basic phenomena?

The students participating in the courses of electromagnetism during the years 2004-2005 were tested in the beginning of the courses by using the well known CSEM [4] test. Based on the test results, a group of 5 students from the whole group were invited to video taped semi-structured interviews. The chosen students were physics majors and represented both genders and they ranked around the average value of the CSEM test. In the interviews the students were asked to explain their reasoning behind their answers to the CSEM test questions 6 and 13. Students had possibility to use figures in explaining their reasoning. Based on the CSEM test questions, additional questions were formulated that they dealt with the concept of fields, vectors and the applications of those concepts.

Results

In the following paragraphs, the student's explanations to the CSEM test questions 6 and 13 are presented with details.

Analysis of the electric force and field

The students were asked to give answer to the CSEM question number 6 in the interview (Figure 1). In addition they were asked detailed questions concerning the problem. The students' responses to the questions are shown in Table 1.

Figure 1. CSEM 6: Which of the arrows is in the direction of the net force on charge B?



Force vector addition was used in most cases to summarise the forces on the charge B. Some students however draw the repulsive force vector in such a way that it ended at the charge B rather than originating from it, whereas in case of attractive force the force vector originated correctly from the charge B, leading to a confused graphical representation of the forces as in figure (2).

Figure 2. Students' number 2 and number 4 representation of Coulombian forces acting on charge B.



Next the students were asked to draw or explain what is the electric field in the location of the charge B. This is referred in the table as the "Force -field relation". No student could give any answer to this question. In case of a single point charge most students were able to draw field lines originating from the charge i.e. the radii referred in the table as "Field line representation". Some students interpreted also correctly that the line density is proportional to the field strength. Two students of five told that the field is stronger closer to the charge and weaker further away from it, but they could not attach this information in the field line representation thus they could not draw an electric field vector in an arbitrary point. One of the students claimed that the field magnitude remains the same along the field line. Similarly to the "Force-field relation" in the case of two charges (A and C) it was difficult for the students to use only the field line representation to estimate the direction and the magnitude of the electric field at the observation point B.

	Table 1. Stud	ents' resp	ponses to t	the CSEM to	est question 6 and	d detailed conceptions
Studen	tAnswer in the	e Force	Vector	Force -fiel	d Field line	Electric field vector in
	test (correct	vector	addition	relation	representation	arbitrary point
	answer e)			(Two	(One charge)	(Two charges)
				charges)		
1	e	OK	OK	NO	OK	NO

2	b	NO	NO	NO	NO	NO
3	e	OK	OK	NO	NO	NO
4	e	OK	OK	NO	OK	NO
5	e	OK	OK	NO	OK	NO

The above results suggest that students have qualitative ideas about repulsive and attractive electric forces and some students use the Coulomb's law and the referring electric force vector. However, the electric field line representation does not include vector character and thus no further interpretations for possible electric field vectors are given. The students are not able to discuss properly electric fields, especially in situations where the charge does not interact with another charge.

Analysis of the application of the electric field

While the CSEM test question 6 concerns more of the electric force acting on a point charge the CSEM test question 13 is a direct application of the electric field (Figure 3).

Figure 3: CSEM 13: The figure below shows a hollow conducting metal sphere which was given initially an evenly distributed positive (+) charge on its surface. Then a positive charge +Q was brought up near the sphere as shown. What is the direction of the electric field at the center of the sphere after the positive charge +Q is brought up near the sphere?



The students were asked five additional questions concerning the given setup. The results of the student's answers are collected in table 2.

Firstly the students were asked, how the free charges on the sphere would respond to the point charge in the proximity. This question is represented in the table as "Coulomb repulsion q,Q". Student 3 stated that regardless of the magnitude of the positive point charge brought up near the sphere, all the positive excess charge will be found on the opposite side of sphere. The student 4 gave quite a similar answer in addition to that the side of the sphere nearer to the positive point charge will become electrically neutral. This indicates that only the excess charge responds to the external point charge. Inspired by these kinds of explanations concerning the influence the students were next asked about the forces between the excess charges on the opposite surface of the sphere. This part is indicated in the table as "Coulomb repulsion q_i,q_i". The students 1,3 and 4 gave an impression that the arrengement of the excess charges indicates that the possible Coulombian force between themselves is somehow insignificant any longer. Finally the students were asked about the field inside the hollow sphere referred as "Field inside the conductor" in the table. All the students (including student 2) claimed in the interview that in any case there are excess or external charges present there is always an electric field inside the cavity. Depending to the direction of the resulting field in the cavity it was due to the excess or external charge alone. There was no explanation how all charges and their fields were taken into account.

Table 2. Students ' responses to the CSEM test question 13 and detailled question in the interview.

Student	answer in	Coulomb	Coulomb	Field
	the test	repulsion	repulsion	inside the
	(correct	q,Q	qi,qj	conductor
	answer e)			
1	b	OK	NO	NO
2	е	NO	NO	NO
3	а	OK	NO	NO
4	b	OK	NO	NO
5	а	NO	NO	NO

The results of the interview of the CSEM test question 13 indicate that the students have qualitative ideas about electric influence. The influence is understood by Coulombian repulsion between the external charge and the excess charges of the conductor. The additional questions revealed that the students regard given set up quite complex for applying the Coulombian force between the excess charges. In addition the students did not try to apply electric-field concept to solve the original test question.

Conclusions

These results show that the immature understanding of electric field as vector field is one of the reasons that might explain the students' difficulties to give acceptable explanations to the interviewed CSEM test questions 6 and 13. Vectors, in general, are used successfully by first year students in mathematics, but not in electromagnetics. It therefore seems that our findings are well in line with the conclusions from previous research by Dunn and Melzer [5,6]. The findings lead to the demand for the meaningful usage of various representation models in instruction. Consequently, the learning demand consists of the basic understanding of force vectors and the general electric field model which includes both vector and field line presentations.

In practice students study the electric force acting on a test charge in an arbitrary location in the proximity of a charge distribution. This can be done by giving the force vector both graphical and algebraical representation. The well defined vector charachter of the force can now be taken as a starting point for the step towards the field model. The referring electric field vector in the same point is given as $\overline{\mathbf{F}} = q\overline{\mathbf{E}}$ based on which the electric field should be represented again both algebraical and graphically as it is done in the exapmles of Chabay and Sherwood [7].

The critical step from treating the force acting on a test charge to the field vectors describing the electric properties of surrounding space should be taken cautiously. The students have to be encouraged to make sure of the correctness and coherency of their model. This can be done by giving the students possibility to present their ideas to each others in addition to argue and defend their thoughts. The tutor should offer selected examples and topics as a basis for learning and on other hand to guide the discussion and conclusions. Finally the field line representation can be added as a part of the field model, however, the vector character should be mastered first.

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