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What Physics Should We Teach?

Edited by

Diane J. Grayson

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INTRODUCTION

Soon after arriving in Berlin for the IUPAP General Assembly in October 2002, Jurgen Sahm, outgoing chair of the International Commission on Physics Education (ICPE), approached me and said, "We have never had an ICPE conference in Africa." I took the hint. I consulted with the Council of the South African Institute of Physics (SAIP) to see if we could hold an international physics education conference in South Africa under the joint auspices of the SAIP and the ICPE, and they agreed.

In coming up with a theme, I tried to think what could be unique about this conference. For many years at conferences we have been hearing about students' difficulties with physics topics and about a variety of innovative teaching approaches. What we very rarely hear talks about is the physics itself—how we decide what physics to teach and to whom. There have been enormous advances in Physics in the past 20 years, yet so much of what we teach, especially at high school and undergraduate level, is 100 years old and more. There have also been enormous advances in our understanding of what makes Physics difficult for learners, and how we can select, approach and sequence topics to make them more accessible to learners. The ICPE provides a unique forum for physicists with a deep understanding of their subject matter to come together to debate physics education issues. It therefore seemed appropriate for an ICPE conference to have the theme, "What Physics Should We Teach?" My thanks go to the members of the Advisory Panel who helped identify a number of sub-themes that form the strands for this conference. These strands were:

1. Overcoming fragmentation in physics (integrating physics topics)
2. Blurring the boundaries of physics (relationship between physics and other disciplines)
3. Different strokes for different folks (which groups of students need what kind of physics)
4. Origins and ways of knowing (History and philosophy of physics, epistemology)
5. Skills (skills needed for and developed by physics, e.g. cognitive, mathematical, experimental, entrepreneurial)
6. Conceptual organization (selection, sequencing and development of concepts to increase learning)
7. Physics for today (incorporating recent physics developments, technological applications)

Since each of the strands is important, they ran sequentially rather than in parallel. The conference format was chosen in such a way as to encourage maximum participation and debate. For this reason, the only papers that were presented orally were the plenary talks – all other contributions took the form of guided posters. One and a half hours were allocated to each set of poster presentations, in order to allow for a high level of engagement with the presenters. In addition, together with the Chief Facilitator, Minella Alarcon, each plenary speaker was asked to identify several questions for small group discussions, which followed immediately after each plenary talk.

On the last day of the conference, recommendations were made pertaining to each strand. In reporting the results of the discussions, some reorganisation was done, with a new strand 1, Computational Physics, being added and the old strands 1 and 6 being combined. The recommendations are included as part of these proceedings. The proceedings also contain papers submitted by participants that were found to be acceptable for publication after being peer reviewed and revised where necessary.

A number of important issues were raised during the conference and are captured in the recommendations. I would like to highlight a few of them. Firstly, careful construction of curriculum is vital if students are to come away from Physics courses with more than a collection of random, disconnected facts that are of little interest or relevance to their lives. In the past, it was common for physics curricula to consist of lists of topics, the selection and order of which were guided more by habit or tradition than by cognitive research or sound pedagogy. It is now clear that student learning can be greatly enhanced if the following principles are followed in the construction of curricula:

1. There should be a focus on a small number of fundamental principles that can be used to explain a variety of physical phenomena.
2. The selection and sequence of topics should provide a coherent conceptual framework.
3. The hierarchical structure of physics knowledge should be made apparent.

If we want our teaching to be effective then what we teach should be influenced by what we know about how students learn. It is now widely accepted that students have their own ideas about the world and how it works before they set foot in a Physics classroom. Extensive research has shown that many of these ideas are quite different from scientific explanations of the same phenomena. Thus effective Physics teaching entails facilitating a process of conceptual change. To be meaningful to students and lead to meaningful learning, Physics curricula should explicitly take into account common student alternative conceptions and include specific strategies for helping students develop concepts that are in harmony with the generally accepted body of scientific knowledge.

Physicists like to boast that learning Physics teaches a person useful, transferable skills. This is often true, but it could become true to a greater extent and for a greater number of students if the teaching of a variety of skills were made an explicit, integral part of all Physics courses. Skills that could and should be developed through the teaching of Physics include scientific reasoning skills, such as estimating and giving physical meaning to mathematical equations, experimental skills, such as formulating hypotheses and designing and carrying out experiments, metacognitive skills, such as evaluating one's own level of understanding, problem-solving skills, computational skills and communication skills. Physics is also said to develop critical thinking. Again, critical thinking skills could be enhanced through the inclusion into Physics courses of aspects of the history and philosophy of science, which would help students understand how Physics knowledge is created and be able to judge the validity of knowledge claims made both within the scientific community and in students' everyday lives.

Increasingly the boundaries between Physics and other disciplines are becoming blurred. For many years, engineers, biochemists and other scientists have applied Physics principles to their disciplines, but now there are interdisciplinary fields, such as biophysics and environmental science. The divide between the "human sciences" and "natural sciences" is also blurring, as those physicists who are involved in Physics education research have experienced. The blurring of boundaries is leading to new ways of seeing, interpreting and explaining the world. For example, physicists tend to look for a single underlying principle that can be used to explain observed phenomena and make predictions about phenomena not yet observed. Life scientists, on the other hand, tend to look at the whole context in which a variety of organisms and factors are operating and look for inter-relationships and mutual effects. In addition, scientists tend to think that science is culture-independent, but this assertion is questionable. Whilst it is true that particular experiments can be replicated in different cultural contexts and the same results obtained, what may not be the same is the questions that scientists from different cultures choose to ask or the interpretation they may give to the results obtained. The learning and teaching of physics are even more susceptible to cultural influences. As physicists we know that all scientific knowledge consists of models created by humans at particular times and places, but it is all too easy to present science to students as if it were a body of incontrovertible facts. More focus on the history and philosophy of science will also help to overcome this problem.

The final strand of the conference dealt with the place of contemporary Physics topics in Physics courses. Unlike newer sciences, such as biochemistry, many high school and introductory university Physics courses only include topics that are over 100 years old. Even at higher levels, students are not often exposed to topics with which research physicists are currently engaged. Conceptually, it need not be too difficult to introduce students to some aspects of contemporary Physics if the principles of curriculum development listed earlier are followed and teachers are provided with appropriate professional development. For example, if students have learnt about energy levels in atoms and about superposition when they studied waves, it is not a big conceptual leap to teach them about the superposition of energy levels in solids that lead to energy bands, and then to talk about the energy band structure of semiconductors and the host of practical applications that result.

There are many, many more discussions that I hope will be held in the future about "What Physics Should We Teach"? As a zeroth-order approximation, I suggest we begin with the following:

> *We should teach fundamental physics principles connected within a coherent framework, ordered hierarchically, placed within a historical, philosophical and cultural context, explicitly requiring the development and application of various skills and taking into account student thinking.*

Many, many thanks to all those who have helped with different aspects of organising this conference. I am especially grateful to Sandile Malinga, Sadha Pillay, Robynne Savic, Jan Smit, Jaynie Padayachee, Erna Basson and Ignatious Dire. I am also very grateful to the members of the Advisory Committee who stepped in to keep the last two days of the conference running smoothly after I had to leave to attend to a family crisis.

Diane Grayson
March 2005
Pretoria, South Africa

Citation for the Presentation of the Medal of the International Commission on Physics Education (ICPE) to Laurence Viennot

The Medal of the International Commission on Physics Education of the International Union of Pure and Applied Physics was established in 1979 for the purpose of recognizing contributions to international physics education which are “major in scope and impact and which have extended over a considerable period of time”. At its meeting in Noordwijkerhout in August 2003 the ICPE awarded its medal for excellence to Professor Laurence Viennot.

Professor Laurence Viennot is honoured in this way for her pioneering achievements in research in physics education, for the exceptional standards of both rigour and relevance that she has set, and for the recognition that she has won for the importance of such research, both amongst physicists and teachers of physics.

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PAPERS BY PLENARY SPEAKERS

QUANTUM GRAVITY FOR UNDERGRADUATES?

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On large length scales, our universe is beautifully described by general relativity, Einstein's theory of gravity. Quantum field theory provides an equally elegant description of our universe, valid for small length scales. Further, there are situations in which we expect both quantum field theoretic and general relativistic dynamics to be important. To deal with these problems, we would need a theory of quantum gravity. At the present time, there is no theory able to incorporate general relativity and quantum field theory in a single consistent framework. The two leading candidates for a theory of quantum gravity are string theory and loop quantum gravity.

In this talk, the possibility of introducing students to this exciting field of research, in the undergraduate physics curriculum, is examined. Interesting questions which can be raised include asking if such an inclusion is appropriate, what material could be included and how it could be included, what benefits students may gain and what detrimental effects such an inclusion may have. We use concrete examples from statistical mechanics and thermodynamics, as well as from special relativity to demonstrate our arguments. These examples have been implemented at the undergraduate level at the School of Physics, University of the Witwatersrand.

Introduction

There are two pillars on which present day physics rests: general relativity and quantum field theory. General relativity is the theory of space, time and gravitation formulated by Einstein in 1915. It is concerned with the dynamics of the universe on large length scales - the scales of solar systems and galaxies. Quantum field theory is the theory obtained when special relativity and quantum mechanics are unified into a single consistent framework. It is a theory of quantum mechanics with the basic observables living at space-time events. Through the $SU(3)\times SU(2)\times U(1)$ Standard Model, quantum field theory provides an astonishingly accurate description of the elementary particles discovered so far. Indeed general relativity together with the standard model is consistent with virtually all physics down to the scales probed by particle accelerators, roughly 10^{-18} m, Polchinski (1998).

As yet, there is no single theory capable of incorporating general relativity and quantum field theory into a single consistent framework. It is assumed that such a theory exists. This unifying theory has been named Quantum Gravity.

This last point is subtle and deserves some discussion. A helpful analogy comes from electrodynamics. Imagine we wish to describe the dynamics of a single electron moving in a macroscopic electric field. We could do this by coupling the quantized electron field to a classical electric field. This gives us a perfectly accurate description because we deal with a macroscopic electric field. Of course, we should also be able to describe this situation using both a quantized electromagnetic field and a quantized electron field. In this second description, the electric field is represented as a coherent state of the photon field.

There are situations in which we can use quantum field theory on a curved space and get a perfectly accurate description. We should also be able to employ a description which quantizes the metric and represents space-time as a coherent state of the graviton field. It is the framework in which this second description belongs that is missing.

Since quantum field theory and general relativity are concerned with such different length scales, one may wonder if it is sensible to seek a unified description and further if such a unification is necessary. After all, to compute the trajectory of Mars around the sun (a problem which general relativity answers beautifully) we don't need to worry about quantum corrections and to compute the magnetic moment of the electron (a problem which is in the domain of quantum electrodynamics) we can ignore gravitational interactions.

A unification of gravity and the quantum theory probably is necessary. Firstly, there are problems for which we should expect quantum corrections to space-time to be important. These include the description of the big bang and the description of the physics of small black holes, Hartle (2003). Secondly, there are good theoretical reasons to seek a unified theory. Since the work of Wilson *et al.* (1974), we know that re-normalizable quantum field theories are effective theories summarizing more fundamental short distance physics. This short distance physics involves quanta of arbitrarily high energy and hence takes us into a regime where quantum gravity corrections become important. So, to put our understanding of quantum field theory itself onto a more fundamental footing, we are apparently forced to make sense of quantum gravity. Another good theoretical reason to look for a unification is that general relativity breaks down (at the classical level) at gravitational singularities. One expects that from the point of view of quantum gravity, this breakdown is simply a consequence of neglecting (important) quantum corrections.

There are also good reasons to believe that searching for a theory of quantum gravity will be a fruitful activity. Indeed, most of the revolutions in physics from the last 100 years were produced by trying to resolve the tension between two existing theories. Quantum theory resolves the conflict arising out of the need for energy packets in a statistical mechanical description of black body radiation and the absence of such quantized energies in radiation as predicted by electromagnetism. Special relativity has its roots in the tension between Galilean invariance of Newton's law and the Poincaré invariance of Maxwell's equations. General relativity resolved the conflict between the action at a distance formulation of Newtonian gravity and the finite propagation of any (information carrying) signals in special relativity. Quantum field theory is needed to unify quantum mechanics and special relativity. This suggests that resolving the tension between quantum field theory and general relativity will be an equally fruitful exercise.

There are two popular approaches to the problem of quantum gravity: string theory and loop quantum gravity. They are both abstract theories employing sophisticated mathematical machinery. At this point in time we have no proof that either of these theories provides the correct approach to a quantum gravity applicable to our world.

What we do have however, are paradoxes, arising largely from a study of black hole thermodynamics Susskind (1995), and certain evidence of departures from the way we currently think about nature. These paradoxes arise from combining different pieces of physics, each of which are well accepted. These paradoxes are here to stay: any theory of quantum gravity will have to replace (at least some) standard physical ideas with a more appropriate way of thinking that reduces to our current view in some limit.

Loop quantum gravity and string theory are largely out of reach for the undergraduate student. However, the paradoxes we have mentioned above are accessible to undergraduates, and further, they mesh nicely with basic courses that any undergraduate curriculum should include. We will try to make the case that including this material will strengthen our students' education. The discussion presented in this paper will make use of experience gained mainly from third year projects offered at the University of the Witwatersrand, although we would like to make the case that this material should be included to support the existing course work component of the curriculum. To give the discussion some structure, we will try to answer the following questions: Is such an inclusion appropriate? What material could be included and how could it be included? What benefits would there be for the students? What detrimental effects could such an inclusion have?

In section 2 the projects completed are described. Section 3 is reserved for discussion.

Holography, Hot Black Holes and Cosmic Rays

As a part of the third year of the Physics major course at the University of the Witwatersrand, students are required to complete two projects. One of the projects is an experimental project.

The second project can be experimental, theoretical or computational. Each project is to take approximately fifty hours of work in total. Over the course of the last three years a number of students have completed projects which are concerned with quantum gravity. Three of these projects will be described in this section.

Holography

The thermodynamics of black holes has given a lot of guidance into some of the current research directions being pursued, Susskind (1995). In addition, reproducing quantities like the entropy of black holes are important tests for any proposed theory of quantum gravity.

To compute the entropy of a system, we need to be able to count microstates of the system. Thus to compute the entropy of a black hole, we would need to understand its microstates, which is a question for quantum gravity. However, already at the classical level it is easy to argue that we are forced to associate an entropy to the black hole. Indeed, imagine we have a box containing a gas of uncharged particles, with zero total angular momentum. There is a non-zero entropy associated with this box. Now, drop this box into the black hole. The black hole no hair theorems tell us that the only labels that the black hole carries are charge, angular momentum and mass. Thus, all that can happen is that the mass of the black hole increases. If we assume that the black hole has no entropy, then before the box was dropped we had entropy equal to the entropy of the box; after the box has passed beyond the horizon of the black hole, entropy has decreased to zero. This is impossible so that our assumption that the black hole has zero entropy must have been false. We can easily resolve paradoxes of this type by giving the black hole an entropy which is proportional to its horizon area. Further, it is possible to show that the horizon area of a black hole displays all of the properties we would expect of an entropy.

The association of an entropy to a black hole has a number of far reaching consequences. To explore this idea further, suppose the world is a 3 dimensional lattice of spin like degrees of freedom. The exact value of the lattice spacing _ is not important for our argument. Further, suppose that each site is equipped with a spin which can be in one of two states. A lattice fermion field theory would be a concrete example of a theory of this type. The number of distinct orthogonal quantum states in a region of space of volume V is 2^n where n is the number of sites in V. The logarithm of this number is the maximum possible entropy in V

$$\log (2^n) = n \times \log 2 = V \times \_^{-3} \times \log 2$$

In general, the maximum entropy is proportional to the volume of space. This conclusion would seem to follow in any theory in which the laws of nature are local.

Thus we expect a region of size V to have a maximum entropy proportional to V, which is greater than the entropy of a black hole just big enough to fit in V. By throwing in the correct quantity of additional matter such a black hole would form. Since the entropy of the black hole would be smaller than the original entropy, the second law would be violated.

How could this paradox be avoided? There is no complete certainty yet. Three possible resolutions immediately suggest themselves:

1. Perhaps our initial count of the number of degrees of freedom in V was wrong?
2. Perhaps the second law of thermodynamics is violated?
3. Perhaps the entropy we have associated with the black hole is incorrect?

This project was tackled by Milena Smolic (in 2003) and by Samara Pillay (in 2004). In both cases, these students quickly appreciated the problem. Both of them tried to suggest their own possible resolutions of the paradox.

At present, we suspect that possibility 1 offers the correct resolution. In this case, the maximum entropy of any region of volume V is not bounded by the volume of the region, but rather by the area of a surface bounding V. Thus, it must be possible to describe all phenomena within V by a set of degrees of freedom which reside on the surface bounding V. The number of degrees of freedom should be that of a two dimensional lattice with approximately one binary degree of freedom per lattice site - the world is in a certain sense two dimensional. This guess has now been elevated to the status of a principle - the holographic principle.

Both students reviewed the holographic principle and critically discussed this resolution of the paradox. Milena presented the results of her study at the 2004 SAIP conference.

Hot Black Holes

To give further support to associating an entropy to black holes, one would like to study the thermodynamics of black holes. This naturally suggests that black holes are hot, with a temperature proportional to the strength of gravity at the black hole's horizon. This conclusion was convincingly justified by Hawking (1975) who showed that black holes radiate. The details of these computations are sophisticated and require a good working knowledge of quantum field theory on a curved space-time.

The equivalence principle suggests that a uniformly accelerated observer should also see a hot space-time. This is indeed the case, as was shown by Unruh (1976). We assume that our uniformly accelerated observer starts with a velocity directed anti-parallel to the x-axis. The magnitude of our observer's initial velocity is nearly equal to, but less than, the speed of light. Our observer accelerates with constant acceleration, pointing along the positive x-axis. The asymptotes to the uniform world line give the accelerated observer's horizons.

The appearance of these horizons has far reaching consequences. One can separate the full Hilbert space into the tensor product of a Hilbert space of states for the right hand wedge $\_{W}$ tensored with a Hilbert space for the rest of the space $\_{R}$. To construct the quantum mechanics of the accelerated observer, we should trace over the states belonging to $\_{R}$. After performing this trace, the accelerated observer is described by a thermal density matrix. The temperature experienced by the uniformly accelerated observer, can be read directly from the density matrix.

Although this computation is simpler than Hawking's original analysis, it is still out of reach of the under graduate. To further simplify the analysis, one could study the two point function of a free scalar field. One could compute the correlator $<0|\_(x_1)\ \_\ (x_2)|0>$ where x_1 and x_2 are two events on the uniformly accelerated observer world line. Further, the result is expressed in terms of the uniformly accelerated observer's proper time coordinate. This can be compared to $_T<0|\_(t,\mathbf{0})\ \_\ (0,\mathbf{0})|0>_T$ with **0** the null spatial three vector and where $|0>_T$ is a hot vacuum - one that is populated with particles according to
the Boltzman weight. One finds that the above two correlators are equal provided that we identify the acceleration of the uniformly accelerated observer a with the temperature T according to the formula

$$kT \times 2\pi\ c = a.$$

This is the formula originally obtained by Unruh.

Three students have tackled this project, Dennis Ovccinna (in 2003), Milena Smolic (in 2003) and Samara Pillay (in 2004). Milena and Samara performed the two point function computation described above. Dennis used these correlators to compute photon emission and absorption rates of a two level charged system carried by the accelerated observer and compared these to photon emission and absorption rates of a two level charged system immersed in a heat bath.

Cosmic Rays

It is of vital importance that we search for possible experimental guidance in formulating quantum gravity. The energies at which quantum gravity effects become important are well beyond what can be reached in any existing particle accelerators. There is however evidence suggesting that present astronomical observations can already be used to probe quantum gravity

Konopka et. al. (2002). In this project our students explore this possibility. The only tools being used are special relativity kinematics.

There is evidence from both loop quantum gravity and from string theory that the standard dispersion relation $E^2 = c^2p^2 + m^2c^4$ will be replaced with a new relation. At leading order one can expect $E^2 = c^2p^2 + m^2c^4 + \_p^3$ with the coefficient _ being dependent on the specific theory of quantum gravity that is being studied. At present the computation of α is not under control. Probably the simplest setting in which this modified dispersion relation will have an impact is in two particle threshold kinematics. Using two particle threshold kinematics one can predict, for example, a cut off in the energy of cosmic rays at around 5×10^{19} eV, the so called GZK bound. The AGASA experiment has observed about 20 events which are well above this cut off. By using the modified dispersion relation the GZK bound is also shifted. Perhaps these 20 events are evidence for a modification in the usual dispersion relation?

To be concrete, we will now summarize the computation for the GZK bound computation. The process we consider comprises of a high energy proton (p) interacting with the cosmic microwave background (i.e. with a photon _) to produce a lower energy proton and a pion (π)

$$p + \_ \_ p + \pi.$$

Assume that the initial proton has energy momentum $(E,\mathbf{p})$, the photon has energy momentum $(E\_,\mathbf{0})$, the final proton has energy momentum $(E_1,\mathbf{p}_1)$ and the pion has energy momentum $(E_2,\mathbf{p}_2)$. The energy E_ is set by the cosmic microwave background. The conservation of energy momentum implies that

$$E + E\_ = E_1 + E_2, \qquad \mathbf{p} = \mathbf{p}_1 + \mathbf{p}_2.$$

To find the threshold for this process, we want to find the minimum final energy at which this process is allowed. Thus, we also require that the derivative of $E_1 + E_2$ with respect to $|\mathbf{p}_2|$ is zero. Together with the dispersion relations, these equations can be solved to give E_1.

There are numerous other extensions of this idea. For example, the modified dispersion relations have an impact on the stability of the photon, stability of pions and they allow vacuum Cerenkov radiation.

This project has been undertaken by two students, Martin Cook (in 2003) and Aimee McNamara (in 2004). Martin presented the results of his project at the 2004 SAIP conference.

Discussion

Having presented the details of three student projects, we will now consider the value of them. Firstly, is it appropriate to include material of this type in the curriculum? One way to include material of this type amounts to setting extra tutorial problems that would complement the existing material. These new problems have a distinct character to normal tutorial problems. They are open ended - the student is most certainly not expected to arrive at a single correct answer. As an example, one could ask students to use the modified dispersion relation to see what observable effects they can predict. Questions of this type encourage speculation and hence creative thinking. Further, since students have to predict the size of an observable effect, this creative thinking has to be disciplined. Mastering this process is a big part of developing problem solving skills. In thinking about questions of this type students see that physics is not a complete finished static subject - our understanding has boundaries which we are continually trying to expand. For the projects described above we have found that students were excited and felt that they could participate in this process. Although the question about modified dispersion relations is a simple one, it is a real problem - not an idealization for the classroom. As a result, the solution for the threshold energy is extremely messy. The students who tackled this project were forced to make certain approximations. Since they didn't have a final correct answer to reproduce, they were forced to go back and estimate how accurate their approximations were. Getting to grips with what approximations could be used contributes to an understanding of the underlying physics.

What material could be included and how could it be included? I think that including something like quantum gravity in the undergraduate curriculum must be done with care. The material included must be simple. The goal is not to learn quantum gravity, but rather to set up situations in which students are excited by the inclusion of this material (which is the subject of many popular books and is reported on in the press), and as a consequence are encouraged to think about and explore the material that appears in the undergraduate curriculum. For example, the computations leading to the holographic principle border on being trivial. However, the more they are pondered the more serious the paradox seems. The students who tackled this project started to question the notion of entropy - asking why its defined in terms of counting microstates, what forces it to be proportional to the volume of the system, what modifications in its definition could we tolerate? In this way, the project served as a vehicle to improved understanding. Rather than including the material in a formal way, it could be included as extra tutorial questions. Problems of this type will only appeal to a subset of students. For example, it is only those students who have a good enough grasp of the physics that will appreciate that there is a paradox. If one is dealing with a group of students who are not able to grasp even the basic material, the value of additions of the type we are discussing is questionable.

What benefits would there be for students? We have already discussed a number of potential benefits that I will not repeat. One benefit that I have seen in our students is that they get very excited about the problems. This is in part because they feel that they can make original contributions - a new experience for them. These raise their own expectations. This material also makes contact with physics discussed in popular articles, and hence it makes contact with physics that students already find interesting. In this way, by including quantum gravity one may hope to provide a natural link between this more exciting and glamorous physics, and the physics that our undergraduates need to master, which is often perceived as less exciting.

What detrimental effects could such an inclusion have? There is the danger that students will tend to focus on the more glamorous aspects of the problems introduced and consequently mastering basic foundations may suffer. This seems to be a challenge for what material is to be introduced. By choosing the right types of problems, students should be forced to start asking questions about the basic physics foundations they need to master in order to make progress with the quantum gravity aspects. The projects described above lead to long discussions about things like entropy and Lorentz invariance. A much smaller portion of time was spent speculating on the quantum gravity component. Another danger is that students get a skewed view of physics. There is more to life than quantum gravity. In an ideal world one would like to see problems from a variety of topical areas of physics included in the curriculum. As an active researcher in the field of quantum gravity, I've naturally dealt only with this subject.

Although my arguments may not have been completely convincing, I hope that I have convinced the reader that the possibility of including some of these ideas in the under graduate curriculum is at least one that deserves to be explored.

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THE CORE AND THE BOUNDARIES OF PHYSICS: RELATIONS TO OTHER DOMAINS

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Physics underlies the way things work in the world, and hence is the underlying basis for environmental science, biology, medicine, and materials. However the relation is complex. First, some of the major underlying principles of physics emerge in one way or another in the emergent disciplines, but some of the others don't (conservation laws, symmetries, and the arrow of time being important examples). Second, there are both bottom up and top-down interactions in the hierarchy of complexity; physics usually ignores the latter, preferring to consider the unrealistic idealisation of an isolated system, but they are what enable emergent levels of complexity to have their effective autonomy. This autonomy is described by effective theories that arise out of the fundamental theories; it is important to note that while these theories are not the true fundamental theories, they are nevertheless effective theories in their own domains of application. Physics education should recognise this; the key question is when they are valid (consider Aristotelian and Newtonian dynamics, for example). Third, the way this works out in the human brain is interesting in its own right and also has interesting implications for all teaching; including physics teaching (it implies the importance of both emotion and play in learning). One significant feature is that physics does not imply a causally complete understanding of the physical universe, because it does not take conscious decisions into account. This is a key feature to understand in relation to reductionism.

Applying physics requires a good understanding of context, which determines what theories are applicable and what irrelevant in any particular situation. This in turn can help select what topics might be included in physics courses at various levels that are at the interface with other subjects.

1: Complexity and Structure

True complexity, with the emergence of higher levels of order and meaning, occurs in *modular hierarchical structures*, because these form the only viable ways of building up and utilising real complexity

- With basic physical laws underlying them

-*Everything is made of atoms [Fenymann]*

-*But then how does complexity arise?*

The Hierarchy of Structure:

Psychology

Botany/zoology/physiology

Cell biology

Biochemistry

Chemistry

Physics

Particle physics

Symmetries and conservation

Underlying symmetries imply conservation laws
- matter, energy, momentum

Broken symmetries imply broken conservation laws
-Arrow of time

Conserved quantities remain conserved in a generalised sense BUT
- Matter and energy are lost for all practical purposes [course graining, lost information: hence entropy, heat]
-Momentum is not conserved for all practical purposes [friction converts energy to mainly useless heat]

-Underlying symmetries are hidden in the real world

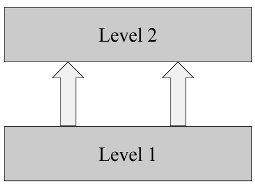
2: Bottom-up and Top-down action

Bottom-up action is when the lower levels of the hierarchy causally effect what happens at the higher levels in a causal way.

Top-down action is when the higher levels of the hierarchy causally effect what happens at the lower levels, in a coordinated way.

- multiple top-down action as well as bottom up action, enables self-organisation of complex systems
- enables higher levels to co-ordinate action at lower levels, and so gives them their causal effectiveness

- is prevalent in the real physical world and in biology, because no real physical or biological system is isolated. Boundary effects as well as structural relations effect top-down action.



Bottom-up causation alone:

Micro forces determine what happens at the higher levels

Bottom-up action

Bottom-up action is when the lower levels of the hierarchy causally effect what happens at the higher levels in a causal way.

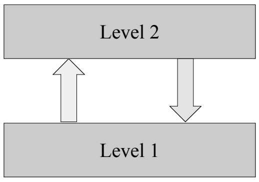
Thus what happens at the higher levels is controlled by what happens at the lower levels

- micro-physics underlies macro physics

- physics underlies chemistry

- physics and chemistry underlie the functioning of the brain

- individual human behaviour underlies the functioning of society



Bottom-up and top-down causation:

Additionally the higher levels control causal effects at the lower levels

Top-down action: boundary and structural conditions

Top-down action occurs by determining boundary conditions or structural conditions

- the gas in a cylinder, heated up by moving a piston

- nucleosynthesis in the early universe, governed by the expansion rate of the universe

- flow of electrons in an integrated circuit

- words typed on the screen of my computer

The motion of the micro-particles in each case is governed by macro conditions

Top-down action: the arrow of time

Top-down action occurs in the determination of the arrow of time.

One cannot tell how a macrosystem will behave in the future on the basis only of the laws of physics and the properties of the particles that make up the system, because time-reversible micro-physical laws allow two solutions - one the time reverse of the other - but only entropy-increasing solutions in one direction of time occur at the macrolevel; this does not follow from the microphysical laws (but quantum measurement introduces an arrow of time).

Physically, the only known solution to this arrow of time problem seems to be that there is top-down action by the universe as a whole, perhaps expressed as boundary conditions at beginning of space-time, that allows the one solution and disallows the other.

Top-down action: quantum measurement

Top-down action occurs in the quantum measurement process - collapse of the wave function to an eigenstate of a chosen measurement system [as well as in state preparation].

-The experimenter chooses the details of the measurement apparatus - e.g. aligning the axes of polarisation measurement equipment - and that decides what set of microstates can result from a measurement process, and so crucially influences the possible micro-state outcomes of the interactions that happen.

The choice of Hilbert space and the associated operators and functions is made to reflect the experimenter's choice of measurement process and apparatus, thus reflecting this top-down action.

Top-down action: mind on world and body

Top-down action occurs from the mind to the body and thence into the physical world:

When a human being has a plan in mind (say a proposal for a bridge being built) and this is implemented, then enormous numbers of micro-particles are moved around as a consequence of this plan and in conformity with it.

Thus in the real world, the detailed micro-configurations of many objects (which electrons and protons go where) is in fact to a major degree determined by the macro-plans that humans have for what will happen, and the way they implement them.

Hierarchical structure:1

Cosmology	Sociology
Astronomy	Psychology
Geology	Physiology
Materials	Biochemistry

Chemistry
Physics
Particle Physics

Hierarchy of causal relations

* ***The right hand side involves goals & conscious choices***

Effective theories

There are both **bottom up and top-down interactions** in the hierarchy of complexity; physics usually ignores the latter, preferring to consider the unrealistic idealisation of an isolated system, but they are what enable emergent levels of complexity to have their effective autonomy

This autonomy is described by **effective theories** that arise out of the fundamental theories

It is important to note that while these theories are not the true fundamental theories, they are nevertheless effective theories in their own domains of application. This depends on context.

Effective theories

Examples:

- Rising sun
- Galilean and Newtonian gravity

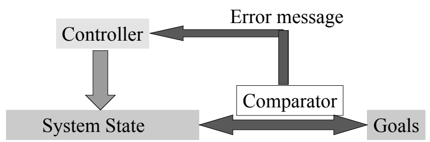
- Aristotelian dynamics
- Fermi weak interaction theory

?? All known physical laws??
Every higher level in the hierarchy – but what is the base??

Physics education should recognise this;
- the key question is when they are valid (consider Aristotelian and Newtonian dynamics, for example)

3: Feedback control systems and information

Feedback control (*cybernetic systems*):



Examples - the temperature of a shower
- the speed of a steam engine
- the direction of an automobile

This is the way information is causally effective

The role of goals and information

The series of goals in a feedback control system are causally effective

They embody information about the system's desired behaviour or responses – living systems are goal seeking ('*teleonomic*')

These goals are not the same as material states, although they will be represented by material states and systems that will make them causally effective through such representations - e.g. the rules of chess or of football

A complete causal description must necessarily take them into account. They exist as emergent properties of the system – they are not embodied in any component on its own.

The nature of goals 1

Homeostasis in the human body:
• Body temperature
• Blood Pressure
• Normal heart rate
• Transport across cell membranes

- each is governed by implicit goals, embodied in the physical structure of the body: Oxidative system, Autonomic nervous system, Immune System, etc
'the human body has literally thousands of control systems in it' [Guyton]
- They occur at all higher scales in the hierarchy
- They have been built in through the adaptive process of evolution and so embody images of environment

The nature of goals 2

Conscious Goals in human activity:
• our actions are governed by hierarchically structured goals at all structural levels in society
• these may be explicit or implicit, qualitative or quantitative

• they are not physical quantities
• they can be represented in many ways, so are effectively an equivalence class of representations
• they are adaptively formed in response to experience: learning takes place in particular contexts
• the mind responds to the meaning of symbols in the relevant social context

Supramolecular chemistry

The key step in the hierarchy: the chemistry of the intermolecular bond (Jean Marie Lehn): where physics underlies information use

- self-organisation directed via molecular information
- enables programmed chemical systems and functional molecular devices
- information storage and read-out via structural features and states of connectivity of a chemical entity
- basis for adaptive systems where error correction takes place and design meets selection
- this in turn enables evolutive chemistry where the features acquired by adaptation are conserved and transmitted

- Chemistry of molecular information

The Effectiveness of Consciousness

Dimensions of consciousness:
- rationality and understanding
- feelings and intentions
- social constructions, e.g. laws

• Concepts are not the same as brain states
- They can be represented in many different ways
• These are all causally efficient: they effect the nature of physical objects in the world

The Brain: Developmental processes

Biological Complexity is regenerated in each individual by a **developmental process**: creation of ordered hierachically structured set of differentiated cells on the basis of genetic information stored in the DNA sequence of bases together with information from the organism and the environment.

- Principles of Darwinian natural selection apply when utilising genetic information in each individual for brain development:
- both because the stored information is far too little to control brain development by itself, Cf. the Human Genome Project: 45,000-100,000 genes but 10^{13} cells and 10^{11} neurons.
- and because this allows the brain to optimally adapt to the local environment (hence *Neural Darwininism*)

Affective Neural Group Selection

• Neurons send out partly-random connections to other neurons

• Those that have a positive survival value are strengthened, others are killed off or allowed to decay
[*Neural Darwinism,* detailed by Gerald Edelman]

• A value system is required to decide which should be regarded as `positive' or `good' [which is also partly decided by use]

• This is provided by the primitive emotions whose seat is the pre-cortical area of the brain, sending out neuro-transmitters characterised in detail by Panksepp [*Affective Neuroscience*]

The basic (primitive) values

The basic emotional systems identified by Panksepp (1998) are the following:

1: The SEEKING system: general motivation, seeking, expectancy
2: The RAGE system: rage/anger
3: The FEAR system: fear/anxiety
4: The LUST system: lust/sexuality
5: The CARE system: providing maternal care/nurturance
6: The PANIC system: panic/separation, need of care
7: The PLAY system: roughousing play/joy

Thus on this view: *it is these [particularly the SEEKING system] that underlie brain development and intellect*
- relates to *evolutionary development* and to *animal behaviour*
- *explains why emotions have been hard-wired in by evolution*

The effectiveness of emotions

• Higher levels of order and meaning are expressed through this process, showing one aspect of how basic emotions can be causally effective

– based in physics but rising above it and not contained in it

They set up a set of implicit goals in the developing brain
These then structure the further brain development and lead to higher goals

Emergent levels of meaning and order hereby control lower levels of developing structure

Physics alone cannot begin to explain this process – it cannot even comprehend the nature of the relevant variables

Teleological behaviour

Variational principles (optimisation of some action function) are at the basis of all physics

- Optics
- *Hamiltonian and Lagrangian dynamics*

- *At higher levels of the hierarchy: we have Darwinian evolution leading to purposive action based on specific goals, designed to optimise ecological niche adaptation*

- *the goals/structures (e.g. DNA sequences) then contain information on history and the environment*

Thus the nature of optimisation/goals changes drastically as we go up the hierarchy: but physics underlies it all.

4: The nature of causality

The key point about ***causality*** in this context is that simultaneous multiple causality (inter-level, as well as within each level) is always in operation in complex systems.

Any attempt to characterise any partial cause as the whole (as characterised by the phrase `nothing but') is a fundamentally misleading position. Indeed this is the essence of *fundamentalism*: claiming a partial truth to be the whole truth.

This is important in regard to claims that any of physics, evolutionary biology, sociology, psychology, or whatever are able to give ***total*** explanations of any specific properties of the mind. *Rather they each provide partial and incomplete explanations.*

The nature of explanation

The key point about explanation is that we take for granted most of the causes in operation in any particular situation and then ignore them, focusing on the particular item of interest that is needed to understand what happens *when all the rest are taken for granted but without which it would not happen*.

She died
- because I sent her to get some cigarettes from the shop
- because the road was wet so the car could not stop in time
- because she was inattentive to the traffic
- because she saw her dog on the other side of the road
- because of Newton's laws of motion
- because her heart stopped beating
- because the ambulance took too long to get here

All are true aspects of the causal nexus that lead to her death

Causality: Bottom-up and top-down explanation

- always multiple levels of explanation that all hold at the same time: no single explanation
so one can have a top-down system explanation as well as a bottom-up explanation*, both being simultaneously applicable*

e.g. why aircraft fly
e.g. effect of legislation on car design
e.g. effect of rules of chess on moves of chess pieces
e.g. effect of mind on human health

In particular: the highest level [intention/ethics] is causally effective

Hierarchical structure: 2

	Ethics
Cosmology	Sociology
Astronomy	Psychology
Geology	Physiology
Materials	Biochemistry
Chemistry	
Physics	
Particle Physics	

Hierarchy of causal relations

5: Emergence and the Laws of Nature

- Laws of nature underlie this
- Permit but do not completely causally control what happens
- Hence are of *fine-tuned nature*
- How they do it is not fully clear – what fine-tunings at the lower levels are needed for the entire higher level hierarchy to exist

The Hierarchy of Structure:

Psychology/ Behaviour

Botany/zoology/physiology

Cell biology

Biochemistry

Chemistry

Physics

Particle physics

Separation of structural levels, independence of levels

Emergent Properties

While emergent properties can in principle be determined from lower level properties, in practice this is not possible

- *chemistry from physics*
- *neuronal behaviour from physics and chemistry*

In practice we have to introduce new phenomenological laws at each level in order to understand the higher level behaviours

"Effective theories" (not always directly deducible from the underlying theory) are the way we attain understanding of the hierarchy of structure).
- *e.g. the Fermi theory of weak interaction*

`Fundamental physics'

Human thought and physics :

- *Human thoughts can cause real physical effects*
- *This is a top-down action from the mind to the physical world*
- *This is not included in what physics deals with*

For example: Chess

- Physics cannot predict the movement of chess pieces as that involves human volition – it cannot predict the choices that will be made

- *Physics cannot even characterize the origin of the possibility space for chess pieces – the set of allowed moves – as that derives from social agreements.*

`Fundamental physics'

In particular this applies to the development of human beings themselves. For example, child development depends on
- *Parental responsiveness to the child's attachment needs*
- *Parental presence or separation from the child*
- *The mother's ability to intuit her child's subjective state, and respond to it appropriately*
[Stevens and Price, *Evolutionary Psychiatry*]

These effects are amongst those that determine the health of the infant, and hence the physical state of its body: thus the micro-states of numerous electrons and protons in the bodies of living beings. They are thus causally effective in the real world.

- *Physics cannot even characterize the relevant variables, let alone the interactions that are causally effective in this context.*

`Fundamental physics'

Human thought and physics :

* At present there is no way to express this interaction in the language of physics, even though our causal schemes are manifestly incomplete if this is not taken into account

-physics accounts for bottom-up actions in the hierarchy, but not crucial aspects of top-down causation

* The minimum requirement to do so is to include the relevant variables in the space of variables considered: to somehow attempt to include consciousness in physics

• *That then makes these variables and their effects a part of physics - or perhaps of fundamental physics [Wheeler, Penrose]*

The challenge to physics

- The challenge to physics is that the higher levels of the hierarchy of complexity are demonstrably causally effective, in particular this is true of *consciousness* and *ethics*;
- But conscious plans and intentions and emotions are not describable in present day physical terms. [This is also related to the arrow of time problem for macro physics]
- *Thus physics has two choices:*

The challenge to physics

Either

- 1. *Extending its scope of description to encapsulate such higher level causal effects*,

  for example including new variables representing thoughts and intentions and so enabling it to model the effects of consciousness and its ability to be causally effective in the real physical world,

or

The challenge to physics

- 2: *Deciding that these kinds of issues are outside the province of physics*, which properly deals only with inanimate objects and their interactions.

  In that case physics must give up the claim to give a causally complete description of interactions that affect the real physical world.

  It cannot even account for a pair of spectacles.

- Hence physics does not by itself provide an adequate basis for metaphysical speculations about the nature of existence.

7: Physics Teaching

- Applying physics requires a good ***understanding of context***, which determines what theories are applicable and what irrelevant in any particular situation.
- This in turn can help select what topics might be included in physics courses at various levels that are at the interface with other subjects.
- Related to this is the fight against *fundamentalism*: the determination to proclaim a partial truth as the whole truth, which is coupled with an inability to relate to context.

Physics Teaching

Affective Neural Darwinism:

Emotions underlie rationality

- which has interesting implications for all teaching, including physics teaching
- it implies the importance of both emotion and play in learning.
- Each topic has an emotional tag that controls learning.

Physics Teaching

- What topics might be included in physics courses at various levels that are at the interface with other subjects?
  – The achievements of physics and the limits of physics
  – Methods of imaging in physics: Waves, interference, information, tomography
  – The importance of context and effective theories
  – Underlying principles: symmetries, broken symmetries, optimisation (variational principles)
  – Complexity and its foundations in physics: relations to biology and the mind

Fundamental physics 1

- *What feature of physics is the key to existence of truly complex structures?*

-What for example allows modular separation of sub-nuclear, nuclear, atomic, and molecular properties from each other in such a way as to allow the development and functioning of DNA, RNA, proteins, and living cells?

- Whatever it is, this must claim to be the `truly fundamental' feature of physics

- *what physics underlies supramolecular chemistry?*

- it is the foundation of the complexity we see

Fundamental physics 2

Is the key:

- the general nature of *quantum theory* (e.g. superposition, entanglement, decoherence) and its classical limit?

- the specific nature of *quantum field theory* and *quantum statistics,* [Yes: stability of matter] and/or Yang-Mills *gauge theory* ?

- the specific *potentials* and *interactions* of the standard particle physics model and its associated *symmetry groups* ?

[Craig Hogan: out of the twenty parameters of the standard model, complexity depends on just five of its parameters]

Fundamental physics 3

Is the key:

- *basic particle properties* (existence of three families of quarks, leptons, and neutrinos, for example)?)?
- *basic properties of forces* (effective existence of four fundamental forces; their unification properties)?

- the specific *masses* and *force strengths* involved?
- the value of *specific constants* such as the fine structure constant?

Or is it

- *The combination of all of these?*
- *But then why do they work together so cunningly?*
- *they are the foundation of human life and of the brain*

THE CORE AND THE BOUNDARIES OF PHYSICS: RELATIONS TO OTHER DOMAINS

Strand 2, Blurring the Boundaries. This theme deals with the interface between physics and other disciplines, e.g. environmental science, biology, medicine and materials. It explores the edges of physics. The point is to consider what topics might be included in physics courses at various levels that are at the interface with other subjects.

Physics underlies the way things work in the world, and hence is the underlying basis for environmental science, biology, medicine, and materials. However the relation is complex.

1. First, ***Emergent Order***: we have a hierarchy of structure, with "atoms" underlying everything. The nature of things higher in the hierarchy is based in the nature of things below.

2. ***Symmetries and conservation***: Some of the major underlying principles of physics emerge in the emergent disciplines, but some of the others don't
   - symmetries imply conservation laws, conserved quantities
   - broken symmetries imply broken conservation laws:
     e.g. the arrow of time
   - conserved quantities remain in some cases (momentum) but with
     aggregated forces so that in practice not conserved
   - conserved quantities (matter) remain conserved but are lost for all
     practical purposes (due to coarse graining) as is the case with energy
     leading to concept of entropy (lost energy/missing information)

3. Information (bits) gives way to ***goals in feedback systems*** which then control behaviour to try to attain the goals. These can be fixed simple systems to varying and indeed adaptive in complex systems
   - variational principles (optimisation: no function/purpose) gives way to

Darwinian evolution (niche optimisation: function/purpose) where the
goals contain information on history and environment

4. There are both ***bottom up and top-down interactions*** in the hierarchy of complexity; physics usually ignores the latter, preferring to consider the unrealistic idealisation of an isolated system, but they are what enable emergent levels of complexity to have their effective autonomy.

5. This autonomy is described by ***effective theories*** that arise out of the fundamental theories; it is important to note that while these theories are not the true fundamental theories, they are nevertheless effective theories in their own domains of application. Examples: rising sun, Galilean and Newtonian gravity. Physics education should recognise this; the key question is when they are valid (consider Aristotelian and Newtonian dynamics, for example).

6. ***Emotions and rationality***: The way this works out in the human brain is interesting in its own right. Emotions underlie rationality (Affective Neural Darwinism) which has interesting implications for all teaching, including physics teaching (it implies the importance of both emotion and play in learning). Each topic has an emotional tag that controls learning.

7. ***Effectiveness of the mind***: Human plans, intentions, and social constructions are effective, thus rationality and emotions are effective as are ethical choices. One significant resulting feature is that *physics does not imply a causally complete understanding of the physical universe*, because it does not take conscious decisions into account. This is a key feature to understand in relation to reductionism.

8. Applying physics requires a good ***understanding of context***, which determines what theories are applicable and what irrelevant in any particular situation. This in turn can help select what topics might be included in physics courses at various levels that are at the interface with other subjects. Related to this is the fight against *fundamentalism*: the determination to proclaim a partial truth as the whole truth, which is coupled with an inability to relate to context.

9. ***Physics teaching***: What topics might be included in physics courses at various levels that are at the interface with other subjects?
    a. The achievements of physics and the limits of physics
    b. Methods of imaging in physics: Waves, interference, information, tomography
    c. The importance of context and effective theories
    d. Underlying principles: symmetries, broken symmetries, optimisation (variational principles)
    e. Complexity and its foundations in physics: relations to biology and the mind

WHAT PHYSICS SHOULD WE TEACH?
(A NEW LOOK AT AN OLD SUBJECT)

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Current crises of science education implies examining physics curriculum, the currently adopted framework "students as a scientist", the philosophical framework of the physics taught, all in light of the changes occurred in modern culture. In the 1960s Schwab's suggested explicit addressing substantive (concepts and conceptions), as well as syntactic (methodology, inquiry) knowledge, topics of the philosophy of science. This change was never accomplished and the history and philosophy of science normally remained considered as an additional to the required in physics class. The suggested here change reconstructs the discipline of physics into "discipline-culture". This change introduces a cell type structure to each physics discipline nucleus (basic principles, paradigm), a body (application of the nucleus principles, "normal" knowledge) and a periphery (rival to the nucleus concepts, unexplained phenomenon, etc.). The new instruction presents physics as a living discourse regarding interpretation of nature, allowing its effective use. Triadic perspective modifies physics teaching from teaching an "engineering" discipline (focused on algorithms) to the one which reveals to students "Pictures of the World", a multifaceted view different from the suggested by positivistic philosophy. The new curriculum recognizes the role alternative understanding and multiple complementary meanings of physics knowledge, making physics closer to the humanities. The new physics curriculum addresses much wider population of students.

Introduction

The year 1968 was an important year in the history of modern civilization. Human rights, anti-war and anti-nuclear demonstrations of extreme intensity in many countries over the world indicated, among others, the change in cultural climate in the modern society. There was a clear turn in the interests of young people into humanistic problems. Before that, science enjoyed the highest prestige due to the belief in the infinite power of science of the ability to solve all major problems of the human society. It appeared, however, that the progress in science was not quick enough and definitely not sufficient to solve the complex problems provided by life. Moreover, it appeared that the progress in science and technology was accompanied with heavy damage to the natural environment (e.g. air pollution and contamination of water natural reservoirs, destruction of forests and so on), threatens to people's health (e.g. radiation effects and risk) and the unexpected and highly undesirable changes in the way of life (e.g. intrusion to private life by means of technology).

At the same time, it is about at that time that a great change took place in humanities – a transition into the post-structuralist era. Contemporary philosophers, Foucault, Derrida and others, introduced such ideas as multiple perspectives and interpretations, rejection of unique sense of text and universal truth, meaning of knowledge as stipulated by historical episteme, deconstruction (changing the meaning following the change of perspective) and so on. The approach of structuralism presents a serious challenge for its being spiritually rich and prolific with regard to the subjects of humanities: art and literature works, philosophical statements, psychological theories. It is often conceived by a novice as clearly opposite (according to the spontaneous knowledge and intuition) to the scientific truth, which is "experimentally verified", "well supported by unbiased dry logic", "rigor calculations", and so on. For many students this deformed image of science is much less attractive than the world of humanities: pluralistic, breaking norms, appealing to fantasy and so on. Is this situation inevitable? Is such an image representative?

To a great extent, the inferior perception of the scientific knowledge is due to the process of impoverishing science (physics) content as presented to the learner in many classes. The main emphasis in such teaching is given to the pragmatic use of scientific knowledge, the knowledge of how-to-do, how-to-use-the-Nature, how to solve the problem.

> The examination system, and the fact that instruction is treated mainly as training for a livelihood, leads the young to regard knowledge from a purely utilitarian point of view, as a road to money, not as the gateway to wisdom. (Russell 1961 p.409)

At the same time, the amount of such knowledge in the modern society grows in a tremendous speed. Facing this problem and seeking the maximum efficiency, teaching converts into instruction and learning – into training. Such an education leaves no space for philosophy of science, which provides the meaning to the scientific knowledge. Pragmatic values of knowledge push away from science (physics) curriculum not only the fact of plural scientific meanings of Nature, but even a single such meaning (explicitly stated ontology), as well as any literacy regarding scientific method (epistemology). As a result, teaching physics often becomes dogmatic, a process of memorizing formulas, identifying standard situations and mastering of the appropriate to them algorithms of solution. Physics becomes an engineering discipline, a mere craft, in a poor sense of this term. Our study was aimed to provide a new look on the physics as a subject for instruction and learning.

Common approach

Physics is commonly presented as a compendium of knowledge delivered in a linear sequence of disciplines: mechanics, hydrodynamics, thermodynamics, electromagnetism, optics, and atomic physics. Each discipline is presented in the form of rules, laws and principles, were possible, mathematically elaborated. Theoretical statements are illustrated with experiments and examples. Well-structured procedures are suggested for problem solving. This is so called “proper knowledge", a standard term in use. In many universities, the types of physics instruction are distinguished in accord with the mathematics used: "calculus", "algebra" and "conceptual". Prospective physicists and engineers take the same general physics course. Prospective physics teachers of high schools are not distinguished from the rest of the students. In fact, this approach was criticized as aback as 1903 by Poincaré:

> Besides the future engineers are other less numerous pupils, destined in their turn to become teachers, and so they must go to the very root of the matter; a profound and exact knowledge of first principles is above all indispensable for them.

The fact of identical subject matter instruction to groups who require different aspects of knowledge testifies for the prevailed inadequate perception of the subject matter, lacking holistic view and focusing on "instrumental" details, regardless the true needs of people who use physics for the great many purposes, including conceptual literacy, which should support them in different areas of human activity.

The linear organization of curricula contents, lacking hierarchy and explicitly stated rationale, in reality, causes students to establish their own intuitive based hierarchy, as well as a rationale of the contents, which are often far from the standard views of physicists. Kuhn termed science, which does not discuss or articulate its own paradigm, but applies it, "normal science. Apparently, this is not the way to endow students (and the prospective teachers on the first place) with the spirit of physics, its values, its nature and commitments. The validity of these aspects of physics knowledge for educators is obvious and, we believe, is equally required by the future researchers (Heisenberg 1977).

In order to suggest another approach to educate people prospective researchers, educators, or simply people literate in physics, one first has to clarify the nature of physics knowledge by establishing its structure. This was essentially the attempt of Schwab (1978) who advocated a science curriculum explicitly revealing the substantive (fundamental ontological), as well as the syntactic (epistemological, conventional, organizational) knowledge of scientific discipline. His attention was, however, given mainly to the nature of the scientific method – enquiry and identifying the building blocks of the science knowledge without pointing at their particular organization in disciplines.

We follow Schwab in addressing the commonplace "subject matter" and argue for a special approach to the physics curriculum, possessing the features characterizing science itself: that is, the discursive nature incorporating a dialogue of ideas (Tseitlin and Galili 2004). We argue for emphasizing the paradigms in a particular discipline, against the background of the rest of the knowledge.

On the first glance, Schwab's emphasis on the enquiry, as representing the core idea of scientific knowledge, supported the metaphor "student as a scientist" with regard to another important commonplace – student. Is this inference really justified? We argue that although, this metaphor has its power in pointing at some elements of learning practice (mainly with regard to problem solving), it fails in many aspects and for many students. What metaphor could then be, then, added? This question we tried to answer.

We first suggest a new curriculum organization, which utilizes the important tripartite cultural code: nucleus, body and periphery. We will define these areas of knowledge and briefly exemplify those addressing Classical Mechanics and Electromagnetism. We will then consider the validity limits of this approach and deconstruct physics as a single body of knowledge. We will address some implications of the new approach and suggest a new metaphor for the student.

Alternative view on the subject matter: discipline as a culture

Inspection of physics, as a knowledge construct, shows that it incorporates specific and highly inclusive discursive areas, which are in fact structurally similar to cultures (Lotman and Uspensky 1978). Physics does not simply describe the world, but interprets it. It imposes particular requirements of form on the texts identified as belonging to it, and it rejects the others, regarded as non-disciplinary ones. In this sense, physics discipline is non-neutral and creates its own virtual world. This feature makes it appropriate to consider physics as some general wholeness – a discipline-culture.

What does this culture comprise? Or, in other words, what makes an aggregate of knowledge a discipline? It is in the structure of the physics discourse that one can find the answer to this question. The meaning of the structure (an arrangement of statements in a hierarchical and meaningfully related manner) is constituted by a group of unique elements that can be called centre (Derrida 1967/1978). Physics practitioners often uncritically identify some of these elements of knowledge as belonging to the regular disciplinary contents. Such are the principles of symmetry, fundamental laws of axiomatic nature, in- and co-variance features of laws and concepts, the principle of causality, etc. The centre includes the core ideas explicitly and tacitly applied by the discipline. Such were, for instance, the ideas of absolute space and time in Newtonian physics. We identify this unique and, in a sense, conventional knowledge as the nucleus of the discipline.

For a given nucleus, all those elements of knowledge, which were produced based on the fundamentals of the nucleus, or those which could be shown as reducible to these fundamentals and consistent with them, constitute the body area of the disciplinary knowledge. nucleus body periphery

Furthermore, there are other elements of knowledge, those whose meanings conflict or cannot be explained by the statements of the particular nucleus. These elements are present on the horizon, or periphery of the structure. We thus expand a discipline to a much wider construct, a super-disciplinary world, consistent and ordered in itself (Fig. 1):

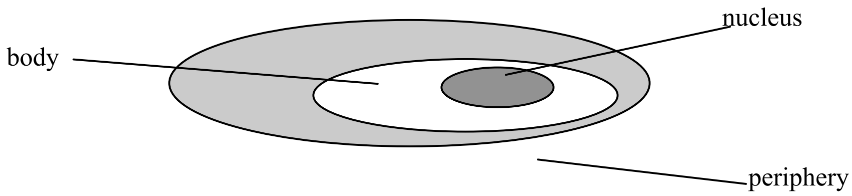

Figure 1. The cell structure of discipline-culture.

The meaning of the new view

The structure provides a tool for taxonomy of different views constituting physics. Common instruction focuses mainly, if not solely, on the body-knowledge of physics disciplines. Many practitioners share the view that this presents the “true” physics, while philosophers of science regard this view as naïve (e.g. Bunge 1973). Actually, Thomas Kuhn’s notion of normal science (Kuhn 1956) signified this school of thought. Einstein, Niels Bohr and his colleagues, among others, considered the nucleus to be the most important part of physics knowledge, the subject for research and investigation. Philosophers of science (e.g. Karl Popper) elaborated this view in details. Other enthusiasts developed approaches marginal with respect to the prevailing of that-day scientific community paradigm. Thus, for instance, David Bohm developed his own interpretation of the quantum theory (e.g. Bohm and Peat 1987). Among the philosophers of science, Paul Feyerabend (1975) ascribed great importance to the development of the ideas belonging, in our terms, to the periphery of the physics discipline.

Our approach should not be interpreted as structuralism. Far from so, the periphery encompasses “other views”, facts and events, incoherent and/or not explained by the principles and axioms of the nucleus. Nevertheless, they are included into the culture. Periphery, the presence of the other, is what makes the change from a discipline to a culture. The discipline-culture is a result of confrontation between the ideas, opposition of the nucleus with its periphery. No progress is possible without a periphery, a competition, a debate and taking over of one idea over another. No particular ordering stated also within the normal area. The tripartite model pretends solely to represent the relationship between the different elements associated with a certain disciplinary knowledge, otherwise left without global arrangement.

Implications for mechanics

The new approach to Classical Mechanics suggests that the teaching emphasizes certain contents as the nucleus. Such are the Newtonian concepts of absolute space, absolute time, material points (or absolutely rigid bodies), the ideas of translational and directional symmetry of space, homogeneity of time, and time-space independence. We find there the principle of inertia (Newton's first law), the concept of inertial mass (as a state preserving factor), the concept of force (central interaction at a distance), and the symmetry of interaction (Newton's third law). It is on this basis, we might not mentioned all, that the normal area of "mechanical knowledge" is constructed, accounting for the variety of natural phenomena and numerous applications.

The periphery of Classical Mechanics incorporates the knowledge at odds with the nucleus. Such are: the relativistic deviations at high speeds, the Michelson- Morley experiment, the Mercury trajectory anomaly, the wave behaviour of mass particles (diffraction, tunnelling), non-central interaction (Lorentz force), thermodynamic irreversibility, etc. These phenomena Classical Mechanics failed to explain; they were explained within other physical disciplines. Instruction of mechanics as a discipline-culture mentions the inability of Mechanics to explain specific issues, instead of ignoring them as "not related to Mechanics".

The peripheral knowledge of Mechanics also includes alternative, now obsolete, mechanical theories from the past, which were surpassed by the Newtonian theory. Such are the Aristotelian theory of motion, the impetus theory of Philoponus and Buridan, and the Cartesian theory of vortices. Thus the discipline-culture includes both historically precedent and subsequent, more advanced knowledge. It remembers its past (what was believed to be true as well as why and how that knowledge was reconsidered and replaced); it foresees the future defeat of its nucleus.

The changes in the curricula are aimed at a culturally rich image of the discipline, the perception of its major paradigms (nucleus). Thus, the often neglected concept of inertia and inertial movement (Newton's first law), is put in the fore to reveal the deep meaning of the ideas previously held in physics regarding motion (Galili and Tseitlin 2003). The fundamental paradigmatic misconception of students with regard to the force-motion relationship (e.g. Viennot 1979, Galili and Bar 1992) becomes an explicit subject.

Implications for electromagnetism

Electromagnetism presents a discipline which is inherently relativistic (even if this fact is ignored in the initial instruction). The cell-structure displays this fact by the nucleus incorporating the postulates of the Special Theory of Relativity, as well as the concept of charge and field. Maxwell equations replace Newtonian axioms; Lorentz force replaces the central interaction at a distance by the vectorial charge-field interaction. The body knowledge of this construct incorporates numerous applications of the nucleus usually taught in traditional courses.

The new approach suggests a discussion of the Lorentz force as a gateway into the relativistic picture of the world (Galili and Kaplan 1997). Similarly, Faraday's law becomes much more than a "flux rule" (Feynman *et al.* 1965), it becomes a crossroad of physics, as it really was for Albert Einstein at the very start of the era of Relativity (Einstein 1905).

The periphery area here includes those phenomena that were unexplained by Classical Electromagnetism: the movement of electrons in atoms, blackbody radiation, violation of action-reaction symmetry of charge interaction, etc. These elements challenge classical electrodynamics and indicate the validity limits of its nucleus. As such, they are presented to the students. The periphery includes ideas from Alhazen's theory of Light (Lindberg 1976), the ideas of Ampère's electrodynamics (Whittaker 1951), the idea of aether and so on. This knowledge presents a contrasting background determining the meaning of the classical electrodynamics for the learner. The curriculum should provide an opportunity to appreciate the discourse on the topics fundamental for electromagnetism, such as space-time absoluteness, speed of light, the unification of electromagnetism with optics, thus creating a valuable conceptual image often missed in the instruction focusing on the normal area of the discipline.

Complementary Deconstruction of Physics

The scientific discourse of physics may create, and usually does so, an image of physics as a unity, a subject of all-embraced fundamentals, history, genealogy, etc. Is it so within the given model?

Consider the above representations of Classical Mechanics and Electromagnetism. We can see that a given element may have different affiliations in each of the considered discipline-cultures. For instance, the Lorentz force presents a foreign idea, which conflicts with the central interaction at a distance, thus belonging to the peripheral zone of mechanics, and at the same time, it belongs to the nucleus of Classical Electrodynamics. Discipline-cultures comprising physics are therefore incompatible, as long as one consider the principles of their nuclei. They might, however, overlay in their normal areas, bodies. Such is, for example, the classical additivity of velocities obtained in the limit of infinite speed of light from the relativistic formulas. This "numerical co-existence" in no way reconciles the nucleus of the two disciplines (Fig. 2). This representation suggests the way to teach the principle of correspondence in physics course.

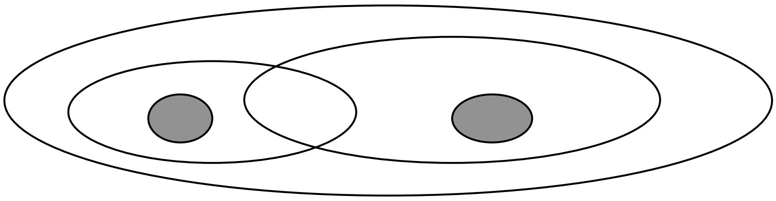

Figure 2. The relationship of two fundamental discipline-cultures represented using the cell-structure.

We thus observe that the relationship between fundamental disciplines in physics is complex and complementary in nature, since they all represent different, equally essential, aspects of nature. One may call them “Pictures of the World”, reflecting their cultural sense.

The fact that physics cannot be regarded as a discipline-culture causes extreme difficulty in attaining its traditionally sought Gestalt. Since the latter represents a goal of many curricula, the question whether it is adequate is of great importance for physics education. Within the suggested perspective, physics, rather, presents a dialogue between different discipline-cultures. The discovery that what had been believed (in the not so distant past) to be a single structure is, in fact, a dialogue of several structures presents a deconstruction (Derrida 1967/1978).

Thus, the science curriculum may present physics as a dialogue between discipline-cultures. The existence of several complementary structures without a unified hierarchy challenges the main tenet of the structuralist dogma (unique nucleus, unique all-embracing structure) regarding physics, which loses its image of a formally rigid, unique construct. This physics might seem less “whole” or even less “scientific” to some people. However, at the same time, discipline-cultures of physics share a lot. They use common, or at least, similar concepts, methodology, approach of modelling, numerical and empirical verification and so on. In other words, they share framework of knowledge and mainly the epistemology. This being similar and different, lack of rigidity and sharing common values by different domains of physical science could be seen as human feature of “family similarity” (to use Wittgenstein’s terminology (1968, §§ 65-71)). For example, the conflicting pictures created by mechanics and thermodynamics are related (albeit not reconciled) by means of statistical physics, incorporating elements of mechanics, as well as such from thermodynamics.

Alternative view on the role of student

The approach of enquiry by Schwab and that of discovery by Bruner (1963) caused the development of a whole orientation of educational system that might be represented by the metaphor “student as a scientist”. It attracted educators (e.g. Driver 1983) as well as philosophers of science (e.g. Neressian 1993). We criticize this conception and, in light of suggested organization of the subject matter, another status of learner.

Although the same term, knowledge construction, might be applied for both the scientist and the learner, one should distinct their different meanings. The features specific for learning science within introductory courses are as following.

1. The learner aims to familiarize him/herself with a whole area of knowledge established by the scientific community. Unlike in science, teacher guides the learner, making his/her way as direct as possible, suppressing all kind of difficulties and uncertainties. The most important scientific discoveries were adventures, not recipe applications.[1] Student does not belong to the discourse, essential for discovery. In short, the conceptual relationship between the learner and scientist can be represented as follows:

$$\frac{\text{learner}}{\text{scientist}} = \frac{\text{study}}{\text{discovery}} = \frac{\text{linear}}{\text{broken}} = \frac{\text{determinicity}}{\text{contingency}} = \frac{\text{disciplinarity}}{\text{discursiveness}}$$

   The study-discovery relationship is understood here as addressing the goals rather than processes.

2. The learner must acquaint him/herself with different theories, metaphysical = person = conceptualizations, forms of presentation, and cultural styles. In a short time students must familiarize themselves with all fundamental physical disciplines, whereas a researcher usually practices a specific method and focuses on a particular problem for a long time.
3. School studies, as mentioned, are short in time, and aim to broad knowledge accumulated over a long time. Therefore, the learner can afford (an inevitable constraint) to construct a superficial knowledge of a range of topics, “to catch the ideas” of a variety of conceptions, having no time and energy for a comprehensive exploration. Therefore, learning does not presume a discovery, although it represents the first step to it.

According to Bibler (1999, pp. 12-14) learning presents an individual activity which does not aim to produce any social commodity. Being only on the edge of productive activity, it is normal even to refrain from such in the course of learning. Such guidance is among the most important functions of the teacher

4. Learning causes a change in the state of the learner (an ability to produce) that cannot be transferred to any other individual. In light of the suggested transition to teaching discipline-culture one may ask regarding the new role of the learner. A new conceptual proportion seemingly is:

$$\frac{\text{learner}}{\text{cultural person}} = \frac{\text{to\_familiarize\_the\_culture}}{\text{live\_in\_culture}}$$

This may suggest a metaphor of anthropologist (for a future consumer of physics) or even a tourist (if the literacy presents a goal), as more appropriate representative image. Culture is then conceived as a personality to be appreciated and explored, rather than a tool to be mastered. This view implies the dialogical nature of learning and may soften the common relationship "human – petrified material" in regular teaching when the subject matter is one “correct” view. Discipline-culture reveals a spectrum of possibilities, asking the learner “whose side are you taking?” – a question that will not leave indifferent many of the learners. This makes physics lesson a “cultural” event.

Implications

The vision employing cultural triadic code is powerful. We will mention here its several implications to the issues relating to physics teaching.

Scientific Revolution

Consider a discipline-culture represented in triadic structure. In parallel with the reigning paradigm of the nucleus, there is (or appears) a conflicting idea located in the periphery. Following the rise of accumulated dissatisfaction of any kind (theoretical, empirical or ideological) with the paradigm and the opposite recognition of fruitfulness of the alternative account provided by the competitive approach a breaking shift occurs and the "movement" of knowledge contents to and from the nucleus (across the domain borders of the discipline-culture) starts. A continual movement of knowledge elements (texts) from the nucleus to the periphery and simultaneous opposite movement of other elements (texts) manifests a revolution. This visualization of scientific revolution is preferable to a simple a chronological chain of theories replacing one another. Within a discipline-culture perspective a revolution appears as a cooperative (synergetic) effect, involving a radical reorganization. The conflicting elements are not “destroyed” or abandoned (as often presented), but rearranged in accordance with the new discipline-culture. The picture of relocation of texts, revision of their status promotes an integrated view of physics and its history, as opposed to the depiction of naïve record of discoveries, as miracles and acts of liberation from the previous blindness or stupidity, which is far from the true account.

The efficacy of the discipline-culture approach is due to the articulated peripheral knowledge zone. The latter appeared neither in Kuhn's (1956), nor, explicitly, in Lakatos' (1970) models. Our model easily adopts such features as protective belts (our normal zone), scientific research program, hard core, and paradigms, exposing the structure and functioning of science.

Conceptual Change

The tripartite model assists in interpreting the learning process. Indeed, it was stated that human cognition is organized in a manner similar to that of the culture, in which the learner is immersed (Vygotsky 1994). Consider the famous example of learning about motion in mechanics. The spontaneous ideas of the learner, often similar to those of Aristotle or Buridan, are originally located in the nucleus of the learner's knowledge. Force is considered to be the cause of movement, and movement – a process of transition between two states. This similarity of onto- and phylogeny suggested the idea of recapitulation. Similar to transition to the Newtonian conception during the scientific revolution of the17th century, the learner is performing a conceptual change.

Indeed, initially it is the periphery that adopts the new ideas in the course of learning. Gradually, the tension arises between the periphery and the pre- instructional conceptions ("schemes of knowledge", Galili and Hazan 2000) located in the nucleus. Eventually, following dissatisfaction with the old knowledge, as opposed to the intelligibility, plausibility and fruitfulness of the new knowledge (Posner *et al.* 1982), this tension (termed "cognitive conflict" in psychology (e.g. Nussbaum and Novick 1982) reaches breaking point – and conceptual change starts.3 At this stage, the body area (normal knowledge) cannot protect the nucleus and the knowledge "flows" into and out from the nucleus. The old content of the latter finds itself in the periphery, "waiting" for the opportunity to come back (Galili and Bar 1992).

This scenario implies that conceptual change requires activities conceptual strengthening the new contents of the periphery, emphasizing the incompatible nature of the new knowledge – basically the constructivist strategy. The more developed the peripheral knowledge and the less developed the normal knowledge, the easier it is to bring about conceptual change: it is easier to teach the novice and young (thin normal area), than to "re-educate" the experienced and adult (well-developed normal area).

Physics Curriculum

Teaching physics as discipline-culture requires corresponded changes in physics curriculum. Researchers pointed to the difficulty of facing a great number of facts, procedures, rules and theories without the guidance regarding their relative importance and validity status. Learners often develop their own organization of knowledge. The common emphasis of the curriculum is often given to application of the new knowledge (technology uses, problem solving). The new curriculum leaves space for discussion of the nucleus content and that of the periphery. Carefully chosen elements of the history and philosophy of science are incorporated in the nucleus and periphery. This knowledge becomes inherent in the subject matter, instead of being relegated to the sidelines as "non-scientific", or merely a "cultural debt". This knowledge is not "additional" any more, but contrasts and thus establishes the meaning of the correct knowledge fostering its adequate understanding. Thus, paradoxically for many, learning about the Aristotelian paradigm of force-motion relationship fortifies understanding of its Newtonian counterpart and so on.

Typology of Learners

The assumption that students might be attracted to the different areas of a discipline culture leads to the correspondent typology of the students according to their cognitive preferences. This perception suggests reconsidering of an oversimplified dichotomy of being "good" or "bad" in physics. Some students may be good in problem solving (body knowledge), others may be interested in the nucleus (the way things are arranged) and still other show the interest in alternative ideas, the debate about the past and future of the discipline and science (those might change physics some day).

Conclusion

We thus conclude that the suggested curricular changes in physics education seek to introduce into the physics class a dialogue of ideas, a constructive discourse of fundamentals in its polyphonic nature. The belief that a science course has to present a single truth apparently failed in addressing the wider public and representing the science of physics. The discipline-culture approach to physics teaching possesses the major features of contemporary culture (plurality and interest in different perspectives). The new approach changes the role of learner and matches different types of learners. Instead of teaching a sequence of isolated physics disciplines, we may teach them in a Kontrapunkt of discipline-cultures.

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1 While scientists describe scientific discovery in highly humanitarian terms (greatest luck, miracle, reconsideration of the old idea), the discovery in the classroom is often presented as resulting a rigid procedure of rules and methods (Baconian perception of the 17th century).

2 This may be regarded as a criticism of the currently popular trend of education by providing research projects, especially those time and effort consuming, already at school classroom.

3 The authoritative persuasion (intelligibility and plausibility of the new knowledge), dissatisfaction with the old knowledge, as well as fruitfulness, feasibility, parsimony, symmetry, and the beauty of the new theory apparently play different roles in science and science education.

SKILLS NEEDED FOR PHYSICS AND DEVELOPED BY PHYSICS

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Based on practices of successful physicists, a set of skills used by experts when doing physics was determined. This set of skills was then checked against the skills that students of physics can develop and acquire in the course of their studies, starting at school level. The paper, however, points out that skills for physics may be the same for all physicists but skills developed by physics vary depending on whether pupils are learning general or pure physics. The paper further points out that the nature of skills for physics are not static but change with time due to the advancement of scientific knowledge and technology. Some comments are made regarding the way physics skills are acquired by experts and novices.

Introduction

For this paper, skills needed for physics has been arbitrarily defined as those skills that practicing physicists or experts have in conducting physics activities primarily in research and development, either in academic institutions or research institutions. Similarly, skills developed by physics refer to those skills that students or novices would end up having after undergoing learning and training in physics.

To determine what these skills are, there is a need to review the meaning of the word physics. The popular meaning is physics as a science of matter and energy. Serway (1996) stated that physics is concerned with concepts and principles, problem solving, and experiments. But skills for the development of physics implicate more than just concepts, principles, problem solving and experiments. Development of physics can refer to generation of knowledge, development of methods and techniques, instruments or equipments to conduct physics. It may also be associated with the needs of a country in which physics is regarded as a tool for development within the context of knowledge and performance based economy and society. Physics input has relevance to present day economic growth and development especially those related to latest findings of materials, techniques and approaches that have commercial potentials. There is also physics for defence and social development. Thus physics seen as a tool for national economic growth, security, environmental care and social development requires a complex management approach that involves experts from other disciplines which therefore must be necessarily collaborative in nature (Haythornwaite *et al*, 2003). This therefore means that physicists need to have other related skills like management and communication.

At the other end of the spectrum, we have the novices who may be at the primary level and secondary or tertiary level. Novices are beginners in pursuit of learning physics. However it must be noted that at the primary or secondary levels of education, it is rather early to conclude that students learning physics will continue to learn physics and opt for careers in physics. In Malaysia in 1999 the proportion of students doing pure science at the equivalent O level was 28 percent of the total student population of the same cohort. (http://www.moe.gov.my/statistik/frinstat.htm). Of these 97 percent of them did physics. The rest of the student population is exposed to physics through the general science subject, which is compulsory for them.

Physics skills developed by physics for the novices are different at different levels. For the school level, the focus is more on the skills related to the processes of science and simple problem solving. It is the curriculum board and qualified officers that determine the skills that these novices should have. Practicing physicists have occasionally been invited as consultants to such board during the time when curriculum is being developed. At the university level, it will be the analytical experimental, research skills and problem solving that will be emphasized. It is the lecturers and professors that design the curriculum through the curriculum committee of the department of physics. Those from the public sector and from the industrial sector are occasionally being invited to provide input so as to make the curriculum relevant to the national and industrial needs of the country. The curriculum is then assessed and evaluated by experts from either local or foreign universities. This is to ensure that the curriculum is of certain academic standing. What it is that is finally being offered to the students can be determined from the teaching and learning materials that are used by the instructors and the students.

Whether it is to excellent students or otherwise, and to the members of the public the perception regarding physics is about the same. Physics is perceived to be dull, dry and difficult for students right from school level. The pull towards physics is therefore negative. It is made worse when career prospects in pure physics are not as attractive as in professional areas. The goals of physics learning do not necessarily correspond with the goals of doing physics vis-à-vis understanding of physics concepts, discovering the laws of physics and developing the skills to do physics. What students learn in schools in the end depend on what is likely to be examined.

Skills needed for physics

Skills are practiced abilities that enable a person to achieve what he aims for. Skills affect speed of doing work, efficiency, and finesse of work. Experts, who are already interested, passionate, serious and committed to physics, develop skills for physics.

Physics skills by experts

Skills for physics can be determined from the types of activities carried out by the experts. We learn from the literature about how Archimedes intuitively discovered his Archimedes principle while in the bathtub. Tycho Brahe made detailed measurements of the planetary motion. Kepler used these measurements to determine the laws governing planetary motion. Newton was eighteen years old when during his eighteen months in rural seclusion "he conceived all the ideas for which the world is grateful (Gamow, 1961, p. 52). Newton investigated nature and cultivated mathematics (ibid, p.53), determined the laws of universal gravitation and invented a reflecting telescope (New College Encyclopedia). Einstein, a renowned physicist of the 20th century and known for his theoretical formulation of $E = mc^2$, worked on heat, electricity and light. He derived the detailed theory of Brownian motion, explained the laws of photoelectric effect and expounded the theory of relativity (Gamow, 1961, p 171).

Physics among Nobel Laureates

Then there is a long list of other physicists and Nobel Laureates who have helped further develop physics to great heights benefiting mankind in various ways.

Starting 1990 till 2003 there are altogether 14 physics Noble Laureates (http://www.nobel,se/physics/laureates/index.html). The scope of physics covered and type of activities carried out were found to be (Figure 1):

1. pioneering contributions in superconductivity, astrophysics,
2. fundamental studies of the properties of condensates,
3. basic work on ICT to be uses in high speed optoelectronics
4. invention of integrated circuits,
5. elucidating quantum structures of electroweak interactions in physics,
6. discovery of new form of quantum fluid, development of methods to cool and trap atoms with laser light
7. pioneering experimental contributions to lepton,
8. neutron scattering techniques, neutron spectroscopy,
9. discovering of new types of pulsar
10. invention and development of particle detectors,
11. discovering methods to study order phenomena in simple systems
12. pioneering investigations in particle physics

Between 1990 till 2003 the areas of physics developed are superconductivity, astrophysics, physics of condensed matter, optoelectronics, integrated circuits, lasers, neutron spectroscopy, simple systems and particle physics. The nature of physics activities are pioneering, fundamental studies, basic, experimental, inventive, discovery, development of physical systems, techniques, methods, devices or apparatus. The spectrum of work therefore covers theoretical, experimental, and practical or applied physics.

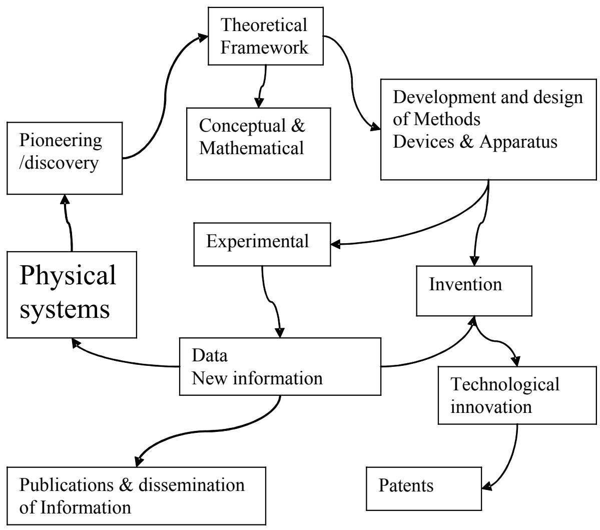


Figure 1: Cycle of Physics

Further exploration on the lives of successful physicists particularly among the Nobel Laureates showed that a number of them were editors of journals, directors of institutions, and project leaders who organized group research activities, collaborated with various other research groups consisting of either academic professors or consultants. A number of them had been responsible in providing leading ideas and leadership in the conduct of their physics activities.

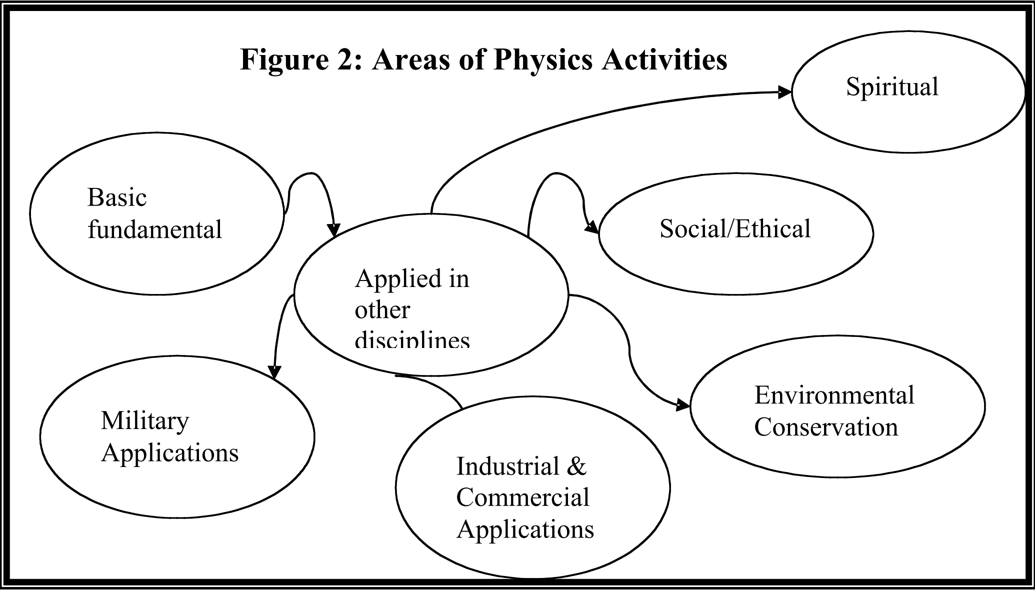
Scope of physics activities

Areas of physics activities as described in Kragh (1999) are summarized in figure 2. During the time of Aristotle, Thycho Brahe and up till now, basic or fundamental research is top priority for the physicists. However needs of a given society at a particular time period influence the nature and type of physics activities carried out by the physics community. The benefits of physics are not for the physics community alone. Knowledge and findings of physics found applications in other disciplines like medicine and engineering. Right throughout history physics community has given assistance to the government, the industry and society.

Research had been carried out in areas of military strength and defence. Research on semiconductors, lasers, condensed matter and lately nano- and bio-technologies have made the economic and industrial sector more vibrant and dynamic. Presently the scope of science hence physics extends into the socio-ethical-moral dimensions. Members of society are expected to be scientifically literate. This has implications to physics education particularly at the critical time when people are found to be disinterested to learn science.

Thus there are different levels of work in physics: the intellectual or knowledge and practical and technical physics at the individual and group level, the administrative at the organizational level, the communication of physics at the public level. Technical physics are the concerns of the physicists. They primarily focus on the physical system under study. These include the theoretical, experimental design and data taking, analytical and applications. Organizational activities refer to the establishment of laboratories, formation of research groups, management of research activities, resources, time and money. Social activities refer to the interpersonal interaction among members within and without research group. Finally communication refers to the transfer and dissemination of information to others. Note that at each level of activities there are specific skills that are required for the growth and development of physics; the intellectual, technical, organizational, social and communication skills.

Figure 2: Areas of Physics Activities



Working culture of experts

Presently experts continue to improve, develop or upgrade further their skills through various means. First the organizational structure has evolved throughout these years. It provides the experts with the necessary material, social and moral support that they need. This makes the working environment more conducive. People are motivated to work. Experts have their own special groups. Members can consult and interact with each other either informally or formally at any time they want to. Through discussions and exchange of ideas individual experts reflect over their work. They then take the necessary action to enhance their skills. The experts write and present their work in seminars, conferences and workshops. These meetings provide experts with opportunities to subject their work, writing and presentation of ideas to scrutiny, check and balance. Even at the level of publication, papers are being refereed and edited before being published. Through these activities experts learn about their limitations, weaknesses or mistakes.

They get feedback. Such feedbacks in turn help experts to develop a sense of what is good and bad practices, of what are right and wrong practices. Experts work in accordance to the standards demanded of them by various assessment bodies.

With modern information communication technology (ICT) connectivity is made available to most experts and professionals. Distance is not a problem to them. Furthermore experts are able to capitalize on the latest technology developed and new knowledge generated to further advance their knowledge and to develop new technologies. The rate of development continues to increase by the minute as a result of such advancement in knowledge and technology. There are also other political and economic forces such as globalization, competitiveness and ISO standards that have in one way or another directly or indirectly influence the physics community to work towards enhancing the quality of work, products and services which in actual fact further enhance and refine the skills for physics

The discussion thus far shows that individual capability matters. However it also points out that experts have ample opportunities to sharpen and refined their skills. They work in an environment that provides them with the necessary social and physical infrastructures. Also take note that a number of these successful physicists had a jump start since they were young. They grew up in environment that was supportive and conducive for them to develop the basic cognitive, intellectual, and practical skills for exploration and discovery of nature. This is true especially those who were born of parents who were professional, or academic professors.

Skills developed by physics

Skills developed by physics refer to the types of skills that students can learn and acquire in the course of their physics learning. There are four areas related to skills that students should acquire with regards to physics. First is the content knowledge base whose breadth and depth help develop students' sensitivity to what should be observed or given attention to. Second is the organisation of information, which needs to be in a hierarchical manner with causal effect relationship. Experts organize their information, in a systematic manner. They exercise logical reasoning. These practices make it easy for experts to remember the knowledge that they have acquired. Studies have shown that this is not true among students.(Brandsford *et al* http://www.nap.edu/html/howpeople1/ch2.html). Third is the representation aspect of physics information. They can be in the form of text, diagrams, mathematical equations, or graphs. Finally it is the ability to determine principles that can be used to solve problems. The skills associated with these are cognitive skills. Apart from these cognitive skills, students are also required to have skills to remember, reason and to apply knowledge for problem solving.

Physics and the students

Students are novices and the practicing physicists experts. As experts they have the theoretical or experimental knowledge content and the skills to conduct physics. This is not true of students. At the motivational level, physicists are internally motivated to do physics. They are curious and have the desire to study and to discover various phenomena demonstrated by physical systems. They take it to be their responsibility to explain the phenomena that they observe. They enjoy doing physics.

Majority of students do physics simply because they have to. Physics is made compulsory to those who want to continue their education in science. Elements of physics have to be introduced in general science subjects. To the policy makers this is a prerequisite to develop a sustainable knowledge based society and who can benefit from the advancement of science and technology. It is believed that members of a knowledge-based society can make informed decision regarding health, nutrition, environment and safety whether at individual or collective level. With survival skills they can also benefit from the presence of technology to manage and administer their everyday living more efficiently and effectively. As the country advances further, civic participation both at the individual and collective is required. People cannot be empowered unless they are scientifically literate. Failing to do that, they become marginalized from mainstream developmental activities.

Unfortunately majority of students' perception toward physics has been more negative. The declining physics enrolment; a world phenomenon is a testimony to this. There is already this inertia that blocks students' readiness and eagerness to learn and to do physics. They are probably not too passionate about physics. Thus they are not wholly devoted or too motivated to learn the subject matter. Furthermore experiences have shown that many young people do not want to become scientists working in research laboratories. There are more interesting and challenging careers like in the industrial sector, or less technical like creative science, science communication as in science centres or careers in the media. Surely the types of skills that are needed by these various groups differ. Some may just need the basic skills of physics like making observations and measurements and they do not need the sophisticated mathematical skills of theoretical physics.

Science camps

There are already several initiatives undertaken by different groups of people to promote public awareness of science. Through activities of the programs participants are given the opportunity to be exposed and to develop science skills in particular physics skills. In Malaysia science camps are getting more and more common. These camps are organized by The National Science Centre of Malaysia, PETROSAINS or sponsored by multinational corporations like BP or Shell.

Through the science activities participants primarily schoolchildren learn to develop their skills. There may be about hundred participants for each camp. It was observed (Norli, 2004) that participating children between the age of 10-12 were ever curious, asking lots of questions and are able to carry out the tasks asked of them. Examples of activities include moving a straw along a string using expiration of air from a balloon, testing the strength of a bridge built from chopsticks.

Skills required for knowledge workers include R & D skills, decision-making, analytical techniques, management skills, strategic thinking skills (Academy of Sciences Malaysia, 2003). School children (of 13 – 17 years old attended by researchers during a science research camp showed an overall 63.2 % in mean score on environmental knowledge and attitude (Syamsul *et al* 2002). National science camps have succeeded in improving student's knowledge. Through activities the level of knowledge has increased by more than two fold.

A colleague of mine told me of her experiences conducting science camps for young children age between 7 -10. Several physics activities were given to the children like using matchsticks to construct the strongest structure, playing with water balloons. According to the colleague, she became just so fascinated that more than 80 percent of the children were having great fun doing all the activities. They were full of curiosities. They asked a lot of questions. They were free to explore their activities. Give children the opportunities to carry out activities in a challenging manner; they are bound to take up the challenge. To her, it is the environment that influences the type of children that they grow up to be.

Science competition

Another situation is students doing physics project for competition (Report, 2003). There were all in all 121 projects of which 22 were from physics. With a maximum scale of 1, the projects were assessed for the following criteria: working together (0.7), clarity 0.68, creativity (0.67), while scientific thinking (0.66). It was found that the best performance was from biology followed by engineering and chemistry. It turned out that those form biology had research scientists either from academic institutions or research institutions as their mentors. This really showed that given the opportunity, students could develop skills that correspond with those of the experts though not at the level of the experts.

Issues in learning physics

There are basically two types of skills that students have problems with. These are skills in giving descriptions and explanations, and learning skills

Skills in giving descriptions and explanations

Observations showed that students had difficulty in describing the phenomena. e.g. a ping pong ball was dropped onto the floor from a certain height. Students were asked to observe and record what they saw. Not many students described how the ball hit the floor, reflected moved up reached a new height but at a lower value compared to the initial height and this happened several times before the ball finally stopped moving. Students tried to provide explanations like it fell due to gravity, and that there is a loss of potential energy and a gain in kinetic energy. Probably students do not have a clear idea of what the words 'describe' and 'explain' mean. Skills by physics should help students know what it is that are expected of them when they do physics. Students should be able to describe the phenomena based on what is visibly happening. Then they should see the nature of the physical phenomena, what factors or variables affect the phenomena. Then they should see how variables are affected by one another, establishing the hypothesis.

Learning skills

Students' forum at a Malaysian educational portal website revealed that school students had several questions regarding how they learn their physics and other science scores. http://www.cikgu.net.my/malay/forum/forummat.php3 (29 Jun 2004). Several statements regarding learning were found in the forum section.

> Suggestion: it is easy to score full marks for science and mathematics. Just memorise the formula and main content. Before test must do past questions.
> Problem: Since I join form 1, I find maths(is) getting more difficult to understand because it has been changed into English and now my maths is getting worse. Can you help give some tips.
> Response: you should understand the concepts that are going to be taught first. Discuss with the teachers. Memorise the formula and read reference book in Malay. If you don't understand than ask the teacher.
> Problem: I cannot follow the lessons in additional maths, chemistry, physics, and biology. Please give subjects effectively. Just remember the tips and formula.
> It's difficult to target science subjects. Please help how to score.
> Response: Science is something that happens around us. It needs understanding in a given topic. Ask teachers or parents if you don't understand. Once understood do some experiments and memorise. Science is easy if we really understand. It is not difficult if we always study, revise and most important understand one by one what is to be expressed. Everything is related to common sense that happens in everyday life. If you really study it is not surprising that you will say science is very easy. Best of luck in trying.
> Response: Read and understand, then memorise what is required. Do mind mapping. If lazy do it in the head. Visualise until you get clear picture of the scientific processes in the mind. Study not to score but to understand. If you still want to target then do past questions.

It was not clear whether these mails were from the teachers or the students. However analysis of the comments made pointed out that physics is learnt through memorization of tips and formula, and practice of past examination questions. The replies given are mixed. There are those who will just want to learn the formula and those who strive to understand. But what is missing is some guide of what one should actually look for when one is doing experiments and what is the meaning of 'to understand physics'.

Students are aware that understanding is needed. This can be achieved by doing experiments. However they still have to commit to memory what they have understood. For some physics is common sense as it happens in everyday life. So all that needs to be done for such students is do mind mapping until the processes involved in actualization of physical phenomena or the conduct of experiments are clear in the mind.

Teachers' preparedness

Teachers are responsible in helping students develop skills needed to do physics. What has to be recognized is the fact that in schools there are physics teachers who do not have the background hence qualification in physics. No doubt these teachers have pedagogical knowledge content but their knowledge of the subject matter may be limited. No doubt we have to thank these teachers for their help to ensure the survival of physics, but it has to be recognized that there is a limit to their understanding of physics work culture. Furthermore in schools teachers have no way or overcoming the exam-orientedness of the school system. The demand to complete the syllabus is always there. There is also the external pressure set by parents on schools that in the end ideals of learner centeredness in education is just a dream rather than a reality.

Physics experts-teachers gap

It is the communities of physics that determine how and in what direction physics activities are to be conducted and developed. The physics experts and the teachers are not really in touch with one another. The situation is made worse when the linkage between teachers and experts is weak. The experts are more into physics than into education, so teachers lack the opportunity to be within the physics environment. Being detached from the physics work culture prevents teachers from being fully conscious of nature of physics and hence they lack the true spirit of practicing physicists. Teachers particularly among the non-option physics teachers, therefore develop their own view of what physics is all about. Pressured by the exam-orientedness of education, classroom teachers are induced to concentrate on completing the syllabus that it is not possible to be completely student-centered. physics learning boil down to acquisition of facts rather than training for the development of cognitive skills needed for knowledge understanding and content acquisition, mathematical skills needed for practical and theoretical work, and skills needed for the development of the right attitude towards physics and the learning of the subject matter.

Experts vs. novices

Students are different. Physicists have one thing in common i.e. the love and the dedication to do physics. Students may not show the same feeling for physics. In the learning of physics or whatever subject for that matter, the psycho-emotive, motivation, social and cognitive dimension of growth and development cannot be ignored. It is the psychological cognitive interaction with the socio-cultural influence affect students' readiness to learn physics. At the level of the novices, teaching of physics cannot focus just on facts and practices of physics but also the psychosocial dimension so this means teachers need not only skills of physics but skills to motivate students to be interested in physics and be able to learn physics.

Situated Learning

Knowledge and learning is situated (Brown *et al*, 1989). Learning methods that are embedded in real situations are not merely useful but needed. Students from the Centre of Applied Science Universiti Kebangsaan Malaysia went for an industrial training programme for eight weeks. They were placed in hospitals at the X-ray units, the paddy factory and Standard Industrial Research Institute of Malaysia (SIRIM). As the students' academic supervisor I visited the students at the various places. What stood out was that they really enjoyed their learning experiences. This is simply because it was hand on minds on method of learning. Whenever they could not understand anything they felt free to ask and what they liked was that they could get the answer immediately. Furthermore their learning was accompanied with in situ demonstrations problems in understanding of what the instructor told them, they could question immediately and get the answer there and then. On top of that their understanding was supported by actual demonstration of the work that they did. But what is obvious the acquisition of skills when training are conducted by the experts and the real environment, are better than otherwise.

Implications towards classroom instruction

Not everyone who does physics wants to end up in the physics laboratory to research in physics. About 10 % of the total population of physics students would want to pursue careers in physics research but the rest may want to enter physics related field; education both formal and non formal, industry, mass media or even management. Those intending to go into research may require high-level computational skills but those who want to go into management need to know something about management like system thinking. How can diversities in background and career inclinations be handled? Less than fifty percent of students enrolled for 1st year physics this session at my university actually chose physics as their first choice. These students are not as motivated as those who chose physics as their first choice. They may not have reached the desired cognitive skills to learn physics on their own. So how do physics lecturers who are subject specialists handle these students who may be cognitively handicapped to learn physics on their own? This will be a great challenge for the lecturers. Students enjoyed hands on minds on learning approach. Whenever they have problems they are not afraid to ask as they get immediate feedback. Present curriculum that is content laden, examination driven hence may not have given serious attention to skill development training. Skills development needs training. This needs time. Lecturers, instructors or teachers have to be provided with the right teaching learning environment if they are to provide students with activities that develop their conceptual and reasoning skills (ASPEN Proceedings, 1995).

Conclusion

In the past learning is meant for the elitist group. However for 21st Century, it is science for all. Very good students can develop the skills to manage information and to solve problems. The challenge at present is how to handle heterogeneous groups of students with different personal and career needs. Students are handicapped by their limited knowledge content and cognitive skills. Furthermore attitude affects students' motivations towards learning. Therefore teaching must be done in a way that takes care of students' interest and readiness to learn. For skills to be developed teaching must be done in a way that moves the students' hearts and minds. Teachers need to facilitate the development of skills and that opportunities to practice need to be given similar to what experts are experiencing. Rather than saying that it is students who do not know this or that it would probably be better to find out how instructors or teachers can improve their communication skills and art of delivery so as to make students cognitively alert and effective.

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Appendix

Summary of Physics Activities & Skills Required by Physicists (Kragh, 1999)

Physicist	Background	Physics area	Activities that require skills
Pyotr Kapitsa (1894-	Son of military engineer	Magnetic moment of atom interacting with inhomogeneous magnetic field	Proposed a method to determine the magnetic moment Perform Experiments of alpha particle in magnetic fields Discovered linear dependency of resistivity on magnetic fields for various metals in strong magnetic fields Developed new and original apparatus based on adiabatic principle Founder editor of journals Organised the institute for physical problems Develop new methods for liquefaction of air with low pressure cycle Developed a series of experiments that lead to the discovery of papers Invented high power microwave generators Became director of institute and head of department
Nicholay Gennadiyevich Basov USSR 1922 -	Father – professor Was in military service	Quantum radio physics – design and build molecular oscillators	Designed & built oscillators Investigated frequency stability molecular oscillator Worked together with pupils to do studies Proposed methods to increase frequency stability Studied transition processes proposed and designed oscillators Designed and constructed quantum and molecular oscillators, amplifiers and lasers Conducted and proposed methods of theoretical studies on use of semiconductors to make oscillators Developed cooperative methods for collaborative work Research in theory and experiments
Lev Davidovic Landau 1908-1968	Son of engineer	Theory of condensed matter	Was head of theoretical department, Professor and Member of the Academy of sciences Discovered, did extensive research and work on construction of theory of condensed matter
Max Born 1882-	Son of professor	Theory of relativity, relativistic electron	Academic lecturer Did experiments on Michelson spectrograph Developed theory of sound ranging, theory of crystals Wrote book on crystals Carried out series of study on quantum theory Carried out investigation of the principles of quantum mechanics, statistical interpretation of quantum mechanics Worked on nonlinear electrodynamics collaborating with

			Infeld Went to India to work with Indian students

Donald A. Glase 1926 -	Businessman father	Electron diffraction	Was teacher of mathematics Studied properties of metallic films evaporated on crystalline metal substrates Carried out experimental study of momentum spectrum of high energy cosmic ray and mesons at sea level Examined various experimental techniques, constructed a number of diffusion cloud chambers Developed ideas that the led to invention of bubble chamber Developed experiments that yield information
Subramanyan Chandrasekhar, 1910	Father Deputy of Auditor General, mother of high intellectual attainments	Theoretical physics, stellar structure Relativity and relativistic astronomy Mathematical theory of black holes	Choose areas amenable to cultivation and compatible with taste, abilities and temperament Accumulated sufficient body of knowledge and achieved view of his own, Able to present ideas in a coherent account with order, form and structure

Summary of expert-novice difference (Gerace, 1993)

	Experts	Novices
Knowledge Characteristics	Large store of domain specific knowledge which is richly interconnected and hierarchically structured through use of integrated multiple representations	Sparse knowledge set that is disconnected and amorphous. Knowledge structure is poorly formed through use of unrelated representations
Knowledge behaviour	Conceptual knowledge impacts problem solving Perform qualitative analysis Uses forward-looking concept-based strategies	Problem solving largely independent of concepts Manipulates equations Uses backward-looking means-end techniques

FUNDAMENTAL PRINCIPLES IN INTRODUCTORY PHYSICS

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The goal of the contemporary physics enterprise is to explain a broad range of phenomena using only a very small number of powerful fundamental principles. Although instructors and textbook authors may see the enterprise this way, this is not the view typically acquired by students in the calculus-based introductory course. The result of conventional instruction is to reinforce the student's belief that there exists a separate formula for every situation, and that the student's task is to figure out which of these formulas to use. Students may even believe that it is the responsibility of the teacher or the textbook to tell them which formula to use! We have developed a new, modern, curriculum, *Matter & Interactions*, which emphasizes the power of fundamental principles, and guides students through the process of starting from these principles in analyzing physical systems, on both the macroscopic and the microscopic level. The continual emphasis on the application of fundamental principles and on the atomic nature of matter makes possible the integration of topics that are traditionally taught as disconnected: mechanics and thermal physics are intertwined, as are electrostatics and circuits. For additional information, see http://www4.ncsu.edu/~rwchabay/mi.

Introduction

Physics is characterized by the search for deep, fundamental principles. The power of physics is based on the idea that from a small number of fundamental principles it is possible to predict and explain a broad range of phenomena. However, despite the intent of physics instructors and textbook authors, many students perceive the calculus-based introductory physics course to consist of a large number of special-case formulas, each specific to a very narrow range of situations. In the typical course students are not asked to analyse novel situations but rather to make small changes to previously solved problems. The emphasis is on specific solution patterns rather than on reasoning from powerful, universal principles.

We have created a new curriculum and accompanying textbook, *Matter & Interactions* (Chabay and Sherwood, 2002), which is structured to make clear to students that there is a small number of fundamental principles, which the students themselves can employ to analyse a broad range of phenomena. In mechanics, these are the momentum principle, the energy principle, the angular momentum principle, and the fundamental assumption of statistical mechanics. In electricity and magnetism, we add conservation of charge and the field concept, as expressed in Maxwell's equations. This emphasis on fundamentals permits the integration of topics that have traditionally been kept completely separate. For example, mechanics and thermal physics are intertwined, and both electrostatic and circuit phenomena are analysed using the same concepts and principles.

Students are continually asked to analyse new situations, different from ones they have seen before, by starting from these fundamental principles.

In addition to its emphasis on starting from fundamentals, the *Matter & Interactions* (M&I) curriculum is modern throughout. From the beginning, it emphasizes the atomic nature of matter, and does not relegate atoms to a final chapter that no one has time for. Students themselves engage in building physical models of messy real-world phenomena, including making idealizations, simplifying assumptions, approximations, and estimates, instead of solving only sanitized problems in which all such modelling has been done silently by the textbook author. As a part of this process, students write computer programs to model and visualize mechanical systems and fields in 3D using VPython (http://vpython.org) as an introduction to computational physics, which has become an equal partner to theory and experiment in the contemporary physics enterprise. Details of the mechanics course are described in Chabay and Sherwood (2004); aspects of the integration of mechanics and thermal physics are described in Chabay and Sherwood (1999). For additional information about the textbooks and curriculum, see http://www4.ncsu.edu/~rwchabay/mi.

Fundamental principles

Students who have completed the introductory calculus-based physics course should see clearly that a small number of fundamental principles can explain a very wide range of phenomena; this should be a central goal of the course. Students should learn to feel capable of applying principles to new problems. They should see the place of classical physics in the larger physics framework (including the atomic nature of matter, quantum mechanics, and relativity), and they should have experience with semi classical analyses. In contrast, the typical rationale given for introductory physics is to learn systematic problem solving, to learn to separate the world into system and surroundings, and to practice applying mathematics. Little attention is given to the larger goal of bringing students to see the unity of physics and the power of a small number of fundamental principles.
The traditional calculus-based introductory physics course has been unchanged for 50 years and is all classical, all macroscopic, with anonymous, featureless objects of mass m and charge q. The theory expounded in lecture is often disconnected from the experiments done in the lab. There is no computational physics, despite the fact that contemporary physics is now characterized as the interplay not only of theory and experiment but also of computation. A serious failing is that the traditional course does not connect to contemporary topics such as materials science, biological physics, nano-science, astrophysics and cosmology, nonlinear dynamics, quantum computing, condensed matter physics, particle physics, or computational physics.

In the traditional calculus-based introductory physics course the fundamental concepts are introduced quite late, and consequently are not seen by the student as having central importance. In a typical introductory textbook force is introduced in chapter 5, energy in chapter 7, momentum in chapter 9, and angular momentum in chapter 12. Consequently, what students see as the most fundamental principle in all of physics is $x = (1/2)\ at^2$, the formula they have used the most.

Traditional instruction focuses on solutions to classes of problems (constant acceleration, circular motion at constant speed, static equilibrium, etc.) rather than on reasoning from fundamental principles. There is a nearly exclusive emphasis on deducing unknown forces from known motion (or lack of motion), with no opportunity for students to experience the power of the Newtonian synthesis, in which motion is predicted from initial conditions and a force law. As a result of this emphasis, students in the traditional course do not see clearly that a small number of fundamental principles can explain a very wide range of phenomena. Rather what comes across to the students is that each situation has its own formula.

During the past 20 years there has been significant research on the learning and teaching of physics, conducted by researchers within the university physics community. One of the central results of this research has been the finding that effective teaching and learning does not come easily, and requires a significant investment of effort and time on the part of both instructors and students. Physics education researchers have developed a variety of improved pedagogical approaches which do in fact improve students' learning of the traditional introductory physics topics.

We argue that it is time to ask a different question: what educational goals are worth such an investment of time and effort? What should students learn in the introductory course? A clear set of educational goals (not just a list of physics topics) needs to be articulated. The goal of the M&I curriculum is to engage students in the contemporary physics enterprise, by emphasizing:

- A small number of fundamental principles, from which students start analyses
- The atomic nature of matter, and macro/micro connections
- Unification of topics, facilitated by the atomic view of matter
- Modelling physical systems, including computational modelling

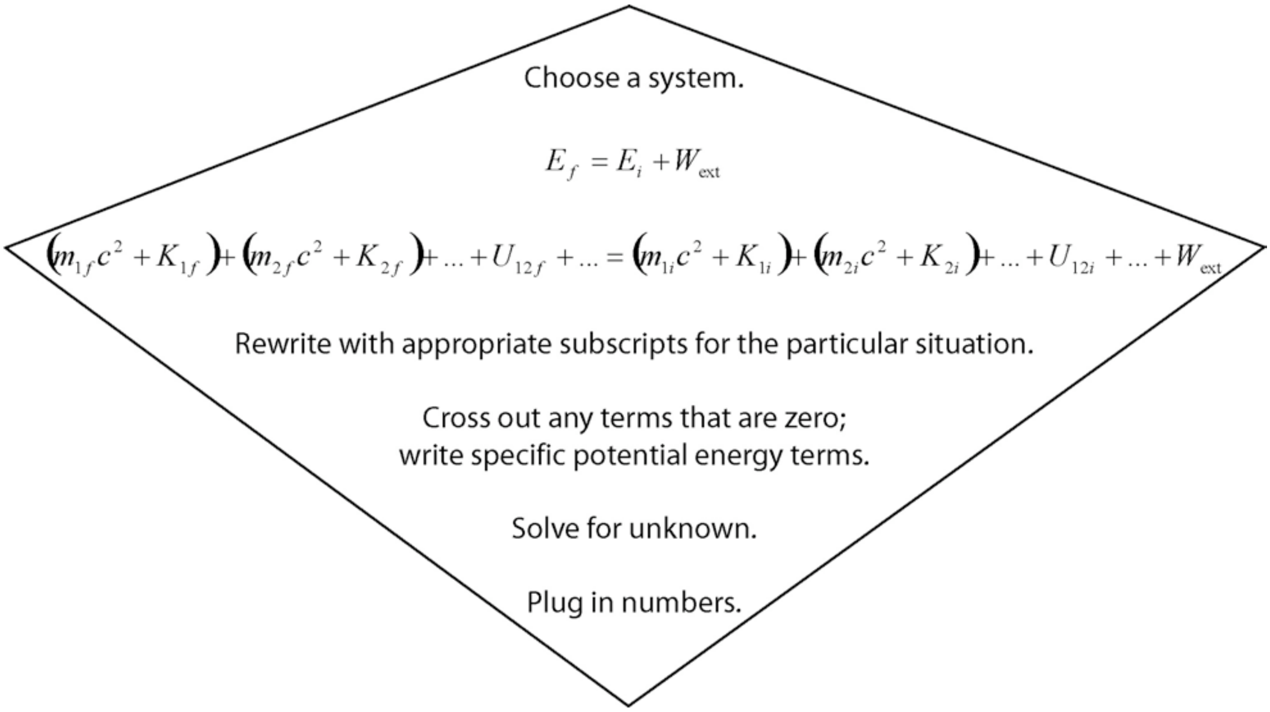
As an example, in mechanics the fundamental principles are introduced much earlier than has traditionally been the case. The momentum principle is introduced in chapter 1 and used from then on; the energy principle is introduced in chapter 4, the angular momentum principle in chapter 9, and the fundamental assumption of statistical mechanics in chapter 10. This in itself makes the fundamental concepts and associated principles stand out as truly central to the enterprise.

In the traditional curriculum, the momentum principle (Newton's second law) is not actually central. In its general form, it is introduced very late in the course. In *Matter & Interactions* it is introduced immediately in chapter 1 in the form $\vec{p}_f = \vec{p}_i + \vec{F}_{\text{net}}\Delta t$, where $\vec{p} = m\vec{v}/\sqrt{1 - v^2/c^2}$. The concept of momentum, and the idea that for a known force law the motion of objects can be predicted into the future in an open-ended fashion, is central to the entire mechanics course. We introduce the Newtonian Synthesis: initial conditions plus the momentum principle plus a force law make possible an iterative update of momentum and position, showing the time-evolution character of the momentum principle. (This picture contrasts with the understandable perception of students that $F = ma$ is essentially an algebraic statement of proportionality, with no sense of time evolution.) Students carry out one or two steps of the Newtonian Synthesis on paper, and then write computer programs to study planetary orbits, spring-mass oscillators, and scattering. We place less emphasis on deducing forces from known motion, such as deducing the support force of an inclined plane on a sliding block.

Teaching students to start from fundamentals

It is important that students be able to approach problems of a kind they've never seen before. This requires starting from a fundamental principle rather than using a solution from some previously solved problem or grabbing a tertiary formula. The idea of starting every analysis from a fundamental principle is a new one to most students, whose previous schooling has stressed memorizing formulas to be used in particular kinds of problems. To these students, it is not obvious how they will obtain a solution (the desired quantity) by starting with an equation that may not explicitly contain that quantity at all. Thus, part of the instruction and acculturation necessarily involves explicit teaching of what it means to start from a fundamental principle, and how to move from the general statement of the principle to a detailed analysis using information particular to a specific situation.

One useful representation was developed by an undergraduate teaching assistant, who himself had taken the course only a year previously (Alex Schriber, personal communication, April 2004). He envisioned the problem solution process as a diamond-shaped flow, first expanding from a fundamental principle, and then contracting to a final solution. Many students found this graphic device extremely helpful in clarifying what was meant by starting from a fundamental principle, and indeed were able to apply it to the solution of problems which they had previously found intractable. Here is an example of his “diamond” approach, starting with the energy principle:



Without this visual guide to the problem solving process, students had typically focused only on the last step: plug numbers into some formula.

Examples of large problems involving modelling

Here are some examples of novel situations which we assign students to analyze as homework problems. Applications of the momentum principle:

- Running students collide (find the force of one student on the other)
- NEAR spacecraft encounters Mathilde asteroid (a detailed statement follows below)
- Finding dark matter (how Vera Rubin discovered this in galaxies)
- Black hole at galactic centre (find the mass from the orbits of nearby stars)

Applications of the momentum principle plus the atomic nature of matter:

- Ball-and-spring model of solid
- Macro-micro connection: Young’s modulus yields inter-atomic spring constant k_s
- Model propagation of sound in a solid; determine speed of sound
- Diatomic molecule vibration: estimate the frequency from inter-atomic k_s

Quantum statistical mechanics of the Einstein solid at the end of the mechanics course: students fit data for the low-temperature heat capacity using k_s obtained from Young's modulus.

Here is the problem statement concerning the NEAR spacecraft mission:

> In 1997 the NEAR spacecraft passed within 1200 km of the asteroid Mathilde at a speed of 10 km/s relative to the asteroid (http://near.jhuapl.edu). Photos transmitted by the spacecraft show Mathilde's dimensions to be about 70 km by 50 km by 50 km. It is presumably composed of rock; rock on Earth has an average density of about 3000 kg/m^3. The mass of the NEAR spacecraft is 805 kg.
> A) Sketch qualitatively the path of the spacecraft:
> B) Make a rough estimate of the change in momentum of the spacecraft resulting from the encounter. Explain how you made your estimate.
>
> C) Estimate the deflection (in meters) of the spacecraft's trajectory from its original straight-line path, one day after the encounter.
>
> D) From actual observations of the position of the spacecraft one day after encountering Mathilde, scientists concluded that Mathilde is a loose arrangement of rocks, with lots of empty space inside. What about the observations must have led them to this conclusion?

These homework problems deliberately transcend the traditional narrow restrictions of introductory mechanics. Classical mechanics taught in isolation is sterile, and can lead to wrong physics. Classical mechanics needs to be embedded in the larger context of thermal physics, relativity, and quantum physics to be authentic to contemporary physics, which is often semi classical. After a traditional mechanics course, a math major in our E&M course said, "Last semester they presented mechanics as a closed axiomatic system. I thought I had learned something of universal validity, and I felt betrayed when I found that wasn't true. I appreciate an axiomatic treatment in math courses, but that's not appropriate in a physics course."

Students' perception of fundamentals

Do students studying the M&I curriculum in fact see and understand the power of fundamental principles in physics? One source of information is students' own reflections. Students were asked to write a paragraph to answer a question such as, "In your opinion, what was the most important concept in chapter 3?" Here is an example of a student reflection:

> In my opinion, the central idea in this chapter was to learn that atoms bonded to each other can be thought of as two balls connected to one another with a spring. Once we understood this concept, we could apply the models of springs from the macroscopic world to the atomic level, which gave us a general idea of how things work at the atomic level. Understanding that gave us the ability to predict vibrational frequencies of diatomic molecules and sound propagation in a solid. It is absolutely amazing how we can use very simple concepts and

> ideas such as momentum and spring motion to derive all kinds of stuff from it. I truly like that about this course.

A second measurement of students' view of fundamentals was made in a problem-solving study. How students use their knowledge reflects the nature and organization of the knowledge. In a protocol study very difficult, novel problems were posed to volunteer students from a traditional course and to students from an M&I course at the same institution. A striking difference in the two populations was that students from a traditional course tried to map each problem onto a problem whose solution they knew, and/or looked fruitlessly for a formula for the particular situation. In these difficult problems this mapping was inappropriate; for example, students tried to use results from uniform circular motion in analysing an elliptical orbit, or to use constant acceleration results to describe air resistance forces (Chabay, Kohlmyer, & Sherwood, 2002). In contrast, even if they were not able to complete the difficult analysis, all M&I students started from a fundamental principle (Kohlmyer, Chabay, and Sherwood, 2002).

Integration

The emphasis on starting from fundamental principles, and the stress on an atomic view of matter, makes possible the integration of topics which traditionally are presented as disconnected subjects. In this section we discuss two examples of such integration: the integration of mechanics and thermal physics (Chabay & Sherwood, 1999), and the integration of electrostatics and circuits. Like other topics in the course, these subjects are presented in such a way that the limitations of the purely classical treatments are clear, and the articulation of classical physics with quantum and relativistic physics is exposed.

Macro-micro connections and the integration of mechanics and thermal physics

It is a peculiar feature of the traditional introductory curriculum that classical mechanics and thermal physics are taught as separate subjects. The first law of thermodynamics, for example, is often presented as though it were completely separate from the energy principle encountered in mechanics. However, classical mechanics alone, without the addition of thermal physics, cannot explain various common everyday phenomena. For example, if you drag a block across the table at constant speed, it would seem that no net work is done on the block, yet the block's temperature rises, and evidently there is an increase in the internal energy of the block (Sherwood & Bernard, 1984). Does this mean that the energy principle applies only to situations where thermal effects are negligible? Or is it a powerful fundamental principle that applies to all situations?

The M&I curriculum intertwines mechanics and thermal physics, by taking a viewpoint that emphasizes the atomic nature of matter. The ball and spring model of a solid is introduced early in the mechanics course. Students hang weights from the end of a long thin wire and measure Young's modulus, then interpret this phenomenon in terms of the ball and spring model of a solid metal. Through a semi classical macro-micro argument we obtain from Young's modulus the effective stiffness of the spring-like inter-atomic bond.

Students measure the spring stiffness and period of a macroscopic spring-mass system, and then write a computer program to carry out a numerical integration of the momentum principle applied to this system, using their measured mass and spring stiffness. They find good agreement between the period of the computer model and the period they measured. Students also study the analytical solution for the motion. From there, we consider a microscopic model of an aluminium wire, considered as a chain of aluminium atoms connected by inter-atomic "springs", whose stiffness the students previously determined from Young's modulus for aluminium. By displacing an atom and observing the propagation of the disturbance through the chain of atoms in the model, it is possible to obtain a numerical prediction for the speed of sound, which agrees quite well with the measured speed of sound in aluminium. This analysis is repeated to find the much smaller speed of sound in lead. It is a striking example of the power of the fundamental principles of physics, plus a simple model for the atomic nature of matter, that hanging weights on the end of a wire leads to predicting the speed of sound!

As a result of this experience with the ball and spring model of a solid, when the energy principle is introduced it is easy to include the thermal energy of a macroscopic object, which is simply energy associated with the microscopic kinetic and potential energy of the atomic balls and springs making up the solid. Thermal energy is always considered along with other energy terms in the application of the energy principle to macroscopic systems.

Since students have previously encountered the idea of discrete electronic energy levels in their chemistry courses, it is an easy step to discussing quantised electronic, vibrational, and rotational energy levels, and photon absorption and emission, in a variety of atomic systems. No attempt at this stage is made to discuss wave functions, superposition, or the relation of wavelength to photon energy. We state that the quantised harmonic oscillator has evenly spaced energy levels, and students work through several exercises and problems that deal with this system.

With this preparation, students in the introductory course find quite accessible a quantum statistical mechanics analysis (Moore and Schroeder, 1997) of the Einstein solid, a ball and spring model in which each atom is modelled as three independent quantised oscillators. Students write computer programs to calculate the entropy, temperature, and heat capacity of nano-particles of aluminium and lead. They are asked to fit their curves for heat capacity as a function of temperature to actual experimental data for aluminium and lead, by adjusting one parameter, the effective stiffness of the inter-atomic “spring”. When a stiffness that is consistent with the value of Young’s modulus is used, the curves fit the experimental data quite well.

This climax to the mechanics portion of the course is a striking illustration of the power of fundamental physics principles and atomic models of matter. The students see that from measuring the stretch of a wire due to hanging weights, they gain sufficient information to predict both the speed of sound and the temperature dependence of the heat capacity of the metal, two properties that initially look totally unrelated to the original measurement.

Macro-micro connections and the integration of electrostatics and circuits

In the traditional E&M curriculum electrostatics and circuits are treated as almost completely separate topics. Electrostatic phenomena are analysed in terms of charge and field, but circuits are analysed in terms of current and potential, and the connection between these two sets of concepts is not made salient. This dissociation undermines the claim that physics can analyse a wide range of phenomena starting from a small number of powerful fundamental principles. Pedagogically, it also removes the concept of electric field from the student’s view, so that by the end of the course students have often forgotten most of what they learned about this concept in the beginning.

In the M&I curriculum both DC and RC circuits are analysed from a microscopic point of view directly in terms of electric field and the microscopic properties of conductors. The key to this microscopic analysis is the surface-charge model of circuits. This model has appeared in the physics literature for many years but has rarely been mentioned in introductory textbooks (Preyer, 2000). Haertel (1987) brought the explanatory power of this model to our attention and stimulated us to explore ways to make this analysis accessible to students in the introductory calculus-based course. The scheme now works well, and students acquire a deep sense of mechanism for circuit behaviour, including the transient in which the steady state is established through feedback. The subsequent connection of this model to the traditional macroscopic analysis of circuits allows students to reinforce connections between field and potential difference, and to see the microscopic components of macroscopic quantities such as resistance.

Classical physics in the larger context

Since so many contemporary applications of science and technology are based on 20th century physics, it is important that students completing an introductory physics course, whether or not they will continue to study physics, see the relationship of classical physics to modern physics. In the M&I curriculum the principles of mechanics and E&M are not narrowly restricted to their limited classical formulations but are obviously embedded in a larger physics context. Momentum and energy are treated relativistically from the start. Students work homework problems on fission and fusion in which the rest masses change. Quantised energy is introduced to help students link the nature of energy at the macroscopic level to the behaviour of energy in the world of atoms. The reality of electric field is made manifest through discussions of retardation effects, in which the field of a remote positron and electron can affect matter for a while even after the remote source charges have annihilated each other. Retardation also plays a role in the transient that leads to the steady state in a simple circuit. A thought experiment involving the mutual repulsion of two protons, viewed from two different reference frames, shows that time must run at different rates in the two frames. All of these discussions serve to situate E&M in a larger context than would otherwise be the case.

Use of the M&I curriculum

The *Matter & Interactions* curriculum is currently in use with students at a variety of institutions within the United States, including small private universities, large state engineering and science universities, four-year liberal arts colleges, and two-year community colleges. Extensive resources are available for instructors who wish to implement this curriculum. For more information, see http://www4.ncsu.edu/~rwchabay/mi.

Acknowledgement

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WHAT PHYSICS SHOULD WE TEACH FUTURE PHYSICS TEACHERS?

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Results of international studies on students' physics achievement and attitude towards science can serve as baseline data on physics content to be taught in school and on physics teaching emphasis at the teacher education level. Exemplars of physics and physics education content of undergraduate physics teacher education programs of selected universities in eight countries provide directions on philosophy of physics education and integration of physics with society, technology, and other disciplines.

Introduction

The quality of student inputs in introductory university physics courses is influenced by the quality of physics teaching in the schools. The quality of school physics teaching in turn is a function of the quality of the undergraduate physics teacher education program and continuing education activities.

In educating teachers on the physics concepts to be taught at any level, difficulties on particular physics concepts and skills need to be considered. The attitudes that students bring to a physics class about the subject, its importance in their lives and in society are useful for prospective physics teachers.

Student Achievement in Physics

The Third International Mathematics and Science Study (TIMSS) 1999 Report (ISC, 2000) listed benchmarks for physics concepts and skills (Table 1) for Grade 8 students (13 years old) from 38 countries, based on achievement test results in physics items. Benchmarks were identified for top 10%, upper 25%, 50%, and lower 25% levels of the students according to their total score in the test. A concept/skill is anchored at a level if at least 65% of the students at this level and less than 50% of the students at the next lower level correctly answered the item testing the concept/skill.

To illustrate, students at the lower 25% level could interpret simple pictorial diagrams (Table 2). Those at the 50% level could also interpret representational diagrams. Students at the top 25% level could further interpret information in a diagram to solve problems. The top 10% students, additionally, used diagrams to communicate knowledge.

Table 1. Some TIMSS 1999 Benchmarks for Grade 8 (13 years old, 38 countries)

Top 10%	**Upper 25%**
*Show understanding of physics principles, including efficiency, phase change, thermal expansion, properties of light & gravitational force - explain that mass and temperature remain constant during phase change - understand that surface of a liquid remains horizontal in a tilted container - recognize that gravity acts on a rocket at rest, while ascending, & when returning to earth *Recognize need for repeated measurements *Apply basic physical principles to solve some quantitative problems & develop explanations involving abstract concepts *Provide answers with two reasons or consequences *Use diagrams to communicate knowledge	*Solve some basic problems related to light, heat and temperature - relate shadow size to distance from a light source - recognize that metal conducts hear faster than glass, wood or plastic - recognize why the height of an alcohol column in a thermometer rises with increasing temperature *Recognize the variables to control in an experimental situation *Draw conclusion from a set of observations *Distinguish an observation from other types of scientific statements *Interpret information in diagrams, graphs & tables to solve problems *Provide short explanations conveying scientific knowledge
59%	**Lower 25%**
*Acquainted with some aspects of energy & motion, light & heat - recognize that a compressed spring has stored energy - recognize that an object will move in a straight line when released from a circular path - identify apparent position of a reflected image in a mirror - apply knowledge of conductors to identify a complete circuit - identify a substance based on whether it is attracted to a magnet - recognize that a person feels cooler wearing light-coloured clothes because they reflect more radiation - recognize that sound needs a medium to travel *Can extrapolate from data presented in a simple linear graph *Extract information from a table to draw conclusions *Interpret representational diagrams	*Recognize some facts about familiar physical phenomena - recognize correct arrangement of flashlight batteries - recognize container where evaporation would be greatest - recognize that objects are visible because of reflected light - recognize that white surfaces reflect more light than coloured surfaces *Interpret simple pictorial diagrams

Table 2. Hierarchy of Skill with Diagrams:TIMSS 1999 Achievement Test Results (Grade 8)

Skill	Benchmark Level
Use diagrams to communicate knowledge	Top 10%
Interpret information in a diagram to solve problems	Upper 25%
Interpret representational diagrams	50%
Interpret simple pictorial diagrams	Lower 25%

For physics content, correct arrangement of flashlight batteries anchored at the lower 25% level, while applying knowledge of conductors to identify a complete circuit was at the 50% level. The lower 25% students recognized that objects are visible because of reflected light; the students at the 50% level could also identify the apparent position of a reflected image in a mirror; and the upper 25% students could further relate shadow size to distance from a light source. For heat and temperature, the top 10% students could explain that mass and temperature remained constant during phase change, while the top 25% students recognized that metal conducts heat faster than glass, wood, or plastic.

Student Attitude towards Science

The findings of another international study, a survey on the Relevance of Science Education (ROSE) involving 38 countries (Sjoberg, 2004), can help guide what physics should be taught to students, as well as to future physics teachers. The survey instrument, administered in 2003-2004, was a 250-item questionnaire using a 4-point rating scale. Grade 10 students (15 years old) rated their out-of-school experiences, what they wanted to learn about, their future job, environment and science classes, themselves as scientists, and science and technology.

Among the initial findings from 21 countries are:

1. Students in all countries strongly agree that science and technology are important for society and providing greater opportunities for future generations;

2. In most countries, students think that science and technology make work more Interesting; and

3. Most students (mainly boys) think that the benefits of science are greater than its potential harmful effects.

These results may reflect adequate emphasis in the science curriculum up to Grade 10 on the importance of science and technology in society. It is hoped that such emphasis will continue in the curriculum, including the physics curriculum.

How did the students perceive their science classes? In all countries, boys liked science better than the girls did (Table 3). In some countries, mainly developing countries, the students liked science very much (Table 4). In developing countries, all students wanted to have as much science in schools as possible. In some countries, girls disliked science very much and did not want to have science in school. These findings argue for encouraging girls to participate and even lead in physics class activities.

While the students generally liked science, very few students wanted to become scientists, with boys wanting to be scientists more than the girls. In developing countries, all students wanted to become scientists, and many wanted to get a job in technology (Table 4). More boys than girls wanted a job in technology. In all countries, the boys were much more interested in working with machines and tools (Table 3) than the girls were. On the other hand, the girls in all countries thought it was much more important to work with people rather than things.

Table 3. Some Gender Differences in Attitude towards Science (ROSE Survey, 2004)

Girls	Boys
*Few want to get a job in technology *It is more important to work with people than with things	* Like science better *Much more interested in working with machines & tools *More think that benefits of science greater than its potential harmful effects

Table 4. Students' Attitude towards Science in Developing and Developed Countries (ROSE Survey, 2004)

Developed Countries	Developing Countries
*Few want to become scientists	*All students want to become scientists *Like science very much *Want to have as much science in schools as possible

In a similar study with 13 year old students in 21 countries (Sjoberg, 2002), among the most popular topics were: computers and what can be done with them; music, instruments, and sound;

and moon, sun and planets. Among the topics least liked were famous scientists and their lives, notwithstanding the ROSE result that girls liked to work with people rather than things. Perhaps, the way that scientists' lives are presented can be looked into, for example, limiting details to what students today can appreciate.

The ROSE findings have implications to physics teaching. Integration of technology of physics applications that deal with machines and tools like computers and other daily life electronic devices, household appliances and common medical equipment can be part of a physics curriculum. Physics teachers can utilize the boys' interest in machines and tools and motivate girls to be actively involved in technology-oriented activities in class.

The girls' greater interest in people than in things can be addressed by inclusion of humanistic aspects of physics, such as the historical development of physics concepts, community-based physics activities, and physics in environment projects.

A physics course at the secondary or tertiary level can include discussion of opportunities in physics-related careers, so that more of the able students can consider becoming a physicist.

Physics Teacher Education Programs

Conceptual difficulties in physics, interface of physics and technology, physics and society have become part of some physics teacher education programs. The physics teacher education curricula of nine universities in eight countries were examined from the Web for possible directions on the kind of physics and physics education courses for future physics teachers.

The philosophy of the Faculty of Education, University of Tokyo provides a direction on the thrust of physics teacher education courses, to wit: "We like to think of humans as entities constantly looking for improvement and growing through social experience and cultural interactions among themselves." The University of Georgia in the United States offers a course that dwells on the philosophy for science teaching, namely, "Philosophy and Leadership in Science Classroom Practice".

One course at the University of Tokyo, entitled "Teaching, Curriculum and Learning", is described as "applied aspects of educational research, based on phenomenology and cognitive science…and clinical studies of schooling. This course likely uses researches on concept learning and will be helpful in identifying and addressing conceptual difficulties of students in physics. Other cutting-edge courses offered are: "Theory of Lifelong Learning", "Educational Physiology", and "Development Brain Science". At the University of South Africa, the course, "Educational Research and Lifelong Learning" provides a research perspective to lifelong learning.

At King's College in England, students with different science majors have common sessions on scientific inquiry and formative assessment based on research on innovative teaching strategies. Teacher education courses at the University of Ontario, Canada like "Authentic Assessment' and "Reflective Teaching and Analysis of Instruction" are indicative of recent trends in physics education. Similar courses, "Reflection on Student Teaching" and "Reflection on Science Teaching", are offered at the University of Georgia. In "Teaching Practice I and II" at the University of South Africa, students build a portfolio; one emphasis is student ownership; and the courses encourage student meta-cognition and self-reflection. Among the courses at Monash University in Australia are studies in education focusing on the theory and practice of teaching. Examples of courses for secondary level are "Beyond the Classroom" and "Teacher's World".

Multicultural education is a major theme in teacher education of the University of South Africa. Kagawa University in Japan exposes students to multicultural studies. Likewise, the University of Georgia offers a course, "Multicultural Education Research". Hiroshima University in Japan also has a course on "Cross-Cultural Study of Education" that physics education majors can take.

For content courses, students at the University of Ontario have, in addition to the usual physics courses, any two of these courses that relate physics with other sciences: Physics for Life Sciences, Physics of the Earth, Shallow Crust Geophysics, Intermediate Biophysics, and Medical Imaging. At King's College, students take other science courses to help them teach science topics other than physics.

At the College of Education in Seoul National University (in South Korea) and University of the Philippines, content courses integrate teaching methods. At Seoul National University, the following courses are offered: "Mechanics Inquiry", "Waves and Optics Education", "Quantum Physics and Epistemology", and "Statistical Mechanics and Thermal Physics Education". Students at the University of the Philippines take the usual physics courses at the physics department of the College of Science.

Computer literacy and using computers in teaching are an integral part of physics teacher education courses in universities like Kagawa University, Seoul National University, University of the Philippines, and University of South Africa. Access to the Internet and e-communication with teachers are commonplace to students in the universities sampled.

Conclusion

International studies on learning difficulties for physics concepts and skills and on attitudes towards science, specifically; physics are sources of benchmarks that can guide the content (concepts, skills and values) of physics and physics education at the secondary and teacher education levels in a country. Similar national studies or school-based or classroom-based research conducted by teachers will be more specific and useful for development of physics or physics education courses.

Physics teacher education programs in some universities indicate a philosophical orientation, emphasis on concept learning, meta-cognition and reflective teaching, multicultural education, and authentic assessment, integration of physics content with teaching methodology and other disciplines, and electronic learning.

Determining what physics should be taught in schools and teacher education programs needs to be a research-based, comparative and consultative process.

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PHYSICS IN SEQUENCE: PHYSICS IN PIECES?

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Given the fact that we have to teach physics sequentially, and to organise the taught content in separate units, there is an obvious risk that our students loose sight of the unifying character of physics, a powerful and marvellously synthetic description of the material world. If we consider this idea as an important target of teaching, and as a chance to motivate our students, then we have to keep a sharp eye on some of our immemorial habits, which might suggest inconsistencies if they were incompletely explained. Some examples will be given and accompanied by teaching suggestions. The importance of some apparently minor aspects of our teaching strategies - "critical details" - will be stressed. At larger scale, some directions of analysis will be proposed to orientate our teaching choices and favour our students' progress toward an integrated understanding of some classical concepts of physics (examples in the domains of optics and waves, fluid statics, perfect gas). The importance of a functional approach, as opposed to a purely numerical one, will be particularly discussed. It will be argued that a unifying functional approach can be adopted at early steps of teaching, so as to present a view of physics which be at the same time demanding in terms of consistency and motivating.

Introduction

Physics is a science that is remarkably efficient at building a cohesive and predictive theoretical description of phenomena, so far as much of the material world is concerned. This feature may be considered one of the main charms of this discipline. But in these days of falling student numbers, obsessive concerns about student motivation can lead us to turn towards other appealing aspects – more particularly, exciting stories, spectacular instruments, dives into the deep past of the universe, (artificially) coloured images of galactic clouds of dust and gas, menacing black holes, etc. These two aspects of physics, coherence on the one hand, dramatic showmanship and illusion on the other, do not naturally go hand in hand, to say the least. The dramatic representation of science excludes what is, reputedly, needed to emphasize the cohesion of physics: abstraction, calculation, effort. Moreover, the economy and coherence of physics, constitutive as these features may be, do not easily withstand the institutional or simply practical conditions behind common teaching practice. These constraints often induce us, teachers, to present a rather fragmented view of science.

The aim of this paper is to examine some aspects of the "life" of coherence and synthesis in our teaching of physics. Some common risks of forgetting these two essential features of physics as well as some suggestions to highlight them will be presented, keeping in mind this question: Can we motivate students by trying to show the power and elegance of physics, at an acceptable intellectual cost?

Coherence and/or economy at risk in teaching

If we adopt the goal of maximising conceptual linkage, then the least we have to do is to avoid sheer inconsistency. But it is surprising how easily we can fall into certain traps in this respect. Some modalities of this risk can be found hereafter; in each case, the practices are extremely common.

"Look at this experiment"

It is a commonplace that science is not the mere contemplation of facts that would spontaneously present themselves in good conditions for their analysis. This said, if we have a beautiful and simple experiment available to show something that is supposedly useful to construct a new concept, we are (legitimately) happy with it. But it may happen that, given the beauty of what is seen and the "simplicity" of the device used, we lose sight of the complete intellectual management that is needed if the students are to really benefit from the experiment. One striking example in this respect is represented in figure 1a (see also Viennot 2003a, ch. 1). Were the first device used inadvertently to "show" rectilinear propagation, thanks to the "rays" visible on the horizontal support, this would also mean that a ray can be dispensed from starting at the source position, situated in this case two centimetres above the support.

And a sarcastic contradictor might well come along and present the second device thus (fig. 1b): "You can see now that light propagates as a wave!" In order to interpret such experiments correctly, it is necessary to understand the "chain" of transformation of light from the source to the visual system of the observer (fig. 2). What unifies the interpretation of figures 1a and 1b is that they can be understood as showing *shadows*, not *rays*, given that the white tracks are only series of lighted points that diffuse light toward the camera (or the observer's eye). If this is not explained, there is a big risk of doing more harm than good, because true coherence appears to be violated.

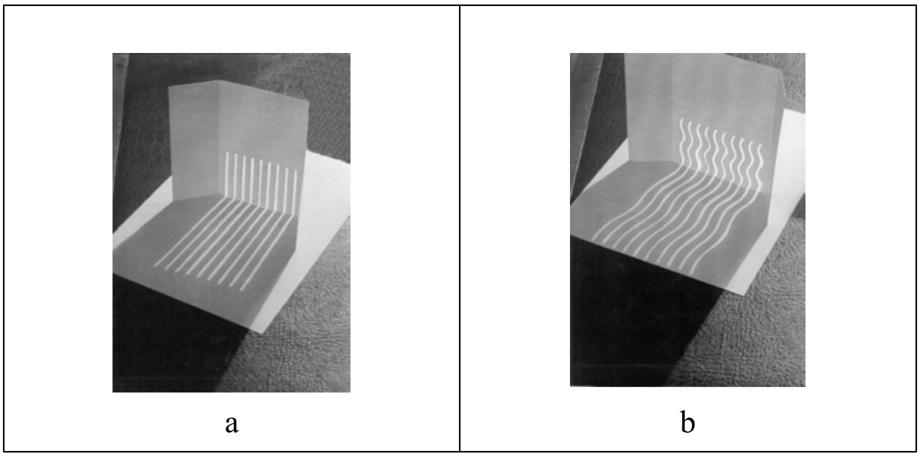

Fig. 1. Two versions of an experiment that can be misleading (Kaminski, pers. comm.).

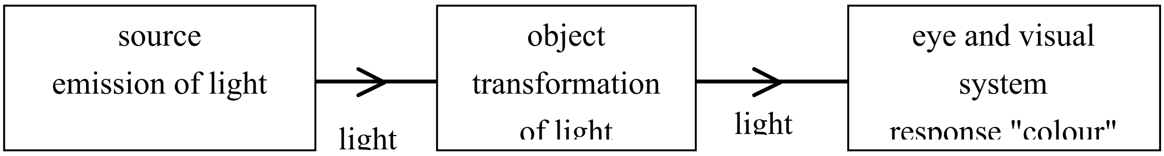

Fig. 2. The chain from the source to the observers' eye: how the information carried by light is transformed (Chauvet 1994: see Viennot 2001 ch.2)

"Look at this image"

The risks of using images in teaching are also to be considered (Colin *et al.* 2001). Let us take the example of the document shown in figure 3. It is extracted from a French book but innumerable analogous versions can be found in textbooks world-wide. The caption is by no means exceptional. In reference to the oblique and parallel lines emerging from the grating, a plane wave is said to propagate immediately after this diffracting object. This is totally inconsistent with the calculation that is universally taught on the basis of this type of diagram, that of the difference in phase between the field at the points situated on these lines and on a given plane surface. The caption, presenting such a plane near the grating as a wave surface, contradicts the very principle of this calculation head-on. However, such a statement is extremely common. It stems at least partly from a reading of the image that is limited to some geometrical surface features, the parallel oblique lines.

What is behind this most-often undetected difficulty is the treatment of a situation in optics using two theories at a time – geometrical and wave optics. How to differentiate these theories and to conciliate their uses in a given situation is a serious question, certainly not solvable with a superficial reading of images that cannot show the phases. An investigation on this point (Colin & Viennot 2002, Viennot 2003b, ch.5) leads to some suggestions. The idea of "backward selection" of the relevant paths of light, starting from the arrival point, is presented as central and is used to characterise the status of the lines drawn on the diagrams. The scope of this paper does not permit me to elaborate on this particular study. This example is just mentioned here to underline how some very common aspects of practice can lead to sheer inconsistency.

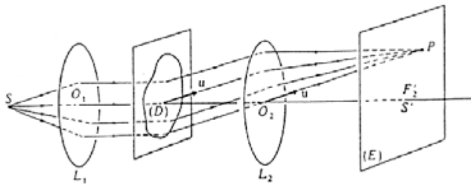

Fig. 3. A diagram presented in a book with the following caption: "The wave fronts associated with the diffracted rays are plane waves perpendicular to their given direction u (...) where k is the propagation vector of the plane diffracted wave".

"Danger: hidden variables"

Formulae have a decisive importance in students' apprehension of physics, sometimes with reductive results. It may happen that a variable on the right side of the "equal" sign is seen as the (only) cause of the quantity expressed by the formula, situated to the left of that sign (Viennot & Rainson 1999). In the case of the well-known relationship, PV=NRT, we can observe what happens to a quantity that is not represented in the formula, and ends up being largely forgotten, as if it were totally irrelevant: the molecular mass. In many textbooks, it is said that all gases behave the same way, insofar as they can be considered as perfect. Presented with this statement and asked which complementary comments they would make, students in an introductory course on this topic (two groups, degree N=14, trainee teachers N=28) did not say a word about phenomena such as diffusion (see also Chauvet 2004) and gravitational behaviour, which are dependent on molecular mass in its respectively inertial and gravitational effects. The fact that the molecular mass disappears from the algebraic expression of the law seems to entail that this quantity can be totally ignored. What is especially striking, in terms of consistency, is that the first thing one can see in some textbooks, next to the claim suggesting that perfect gases are interchangeable, is a picture of a balloon, for instance the Breitling Orbiter-3, partly filled with helium – a gas that is certainly much more expensive than air. What can a student conclude, if he/she is fond of consistency and is left to reflect alone?

Small vs. zero, local vs. global

Fluids provide another opportunity to ruin the beautiful consistency of physics. "Contrary to gases", it is often said, "fluids are not compressible". Approximating the value of the coefficient of compressibility to zero is quite legitimate for many calculations and arguments. But, as Besson remarked (Besson 2004), when it comes to explaining why this is so, "small" is very different from "zero", because "zero" simply blocks the explanation. Thus, if fluids were not compressible at all, waves could not propagate in such media. It would be also impossible to understand how the molecules mutually "inform" one another, so to speak, that something is happening near a piston, which determines a new field of pressure in the whole system. The local and global points of view could not be reconciled. Therefore, in the case of liquids, no systemic reasoning could be conducted properly.

An example of the same type is found in a very common teaching situation. It concerns the gravitational behaviour of a gas, one of the aspects linked to molecular mass. A classic exercise consists in asking, for a hot air balloon of volume V, at which temperature T the internal air should be to achieve the lift-off, given the total mass of the envelope and of the carried mass. Archimedes' principle is the target of such exercises. In order to find the relationship between the density of the internal air and its temperature, it is necessary to know the pressure inside. The text classically reads something like this: "Whatever the temperature of the air in the balloon, its pressure is the same as in the air outside". If you believe this statement without any further specification, you may wonder how the envelope can hold up in the air. Indeed, same pressure inside and outside near each small part of the envelope means no net force is exerted by all the gas. So the envelope would be drawn downwards due to the weight of the carried objects and its own, and could not but fall straight down, and the rest along with it.

In this example, there is a clash between a global approach of Archimedes' principle on the one hand, and a local mechanistic analysis, on the other. What the global perspective ignores is the small difference between the gradients of pressure inside and outside the envelope. Admitting that the pressure is the same inside and outside at the aperture level (bottom), it is not consistent to say that the same balance holds at the top of the balloon. The lesser diminution of the inside pressure with altitude accounts for the fact that this pressure is larger than the external pressure at the top of the envelope, which enables the balloon to hold up in the air. Surprised as they were to discover the problem, some of the students consulted (1^{st} year at university, N=14 interviews, ongoing research) understood the proposed analysis quite easily and wondered why their teachers had omitted to warn them before. Traditionally, local and global points of view are not confronted – another missed opportunity, as far as presenting a unified theoretical analysis is concerned.

These few examples were chosen to illustrate the extent to which we, teachers, can verge on sheer incoherence, and rather frequently. In each case, it is possible to avoid the most absurd strategy and to compensate the risk of giving a fragmented view of physics. The first factors to be introduced in these remedial strategies are of course vigilance and awareness, and for a fine appreciation of the others, research is required. The following section presents some lines of reflection and of action that may prove useful if the basic principle that we keep in mind when teaching is to give our students a view of physics as a highly cohesive and powerful description of the material world.

The power and beauty of physics: bringing linkages to the fore

Specified spotlighting of the taught content: an example from optics

As said above, the word "description" should not be understood as neutral, as if the most basic measurement did not involve a theoretical component. A consensus has been reached in certain extensive areas of physics, and (only) in this sense can it be said that " physics is physics". If we accept this idea, it follows that what we teach is always an orientated and reconstructed view of that consensual "physics". The integrated result of our choices – of content and strategies – is a given spotlighting of the content. The "what-and-how" of teaching constitutes a given picture of physics, just as the angle and the lighting a photographer chooses will determine a specific view of a given landscape. This subsection argues for conscious and coherent choices in this domain, taking elementary optics as an example.

In France's new, research-inspired national syllabus (1993), the chain of transformation of light schematically represented in figure 2 was chosen as a teaching goal – in short, as a "spotlighting" of the content that also provides a way of analysing pupils' reactions. The well-known difficulties concerning light and vision (see in particular Andersson & Kärrqvist 1983, and many authors since) were taken into account by the curriculum designers. In this perspective, the first example given in this paper, i.e. an experiment apparently showing "visible rays" to illustrate rectilinear propagation, appeared as likely to induce misunderstandings. It was, therefore, thoroughly commented on and a *caveat* on the subject was included in the text accompanying the syllabus. It was recommended that rectilinear propagation be introduced via experiments involving shadows, to avoid the risks of misinterpretation linked to "materialised rays". This is an example of how a "spotlighting" of content may orientate teaching strategies coherently toward a specific objective: here, understanding the essential link between light and vision (Viennot 2003a,b).

Along the same lines, it was recommended that optical imaging be introduced by stressing what a lens does to light, on the basis of a diagram like the one shown in figure 4a, instead of immediately moving on to classic diagrams using construction rays (fig.4b). Previous research (Fawaz & Viennot 1986: see Viennot 2003 ch.1) had suggested that this helps understand optical imaging, and more particularly, that any part of the lens can form the whole image and that a real image can be seen without a screen. The challenge in this domain is to have fewer students hang on to such erroneous conceptions, classically referred to as "the travelling image" (see in particular Goldberg & McDermott 1987, and many authors since). Among these misconceptions is the idea that an image will be seen on a nearby wall even if there is nothing between the source and this wall, or that a coin placed on the centre of a lens results in a hole in the image, in a classic imaging situation.

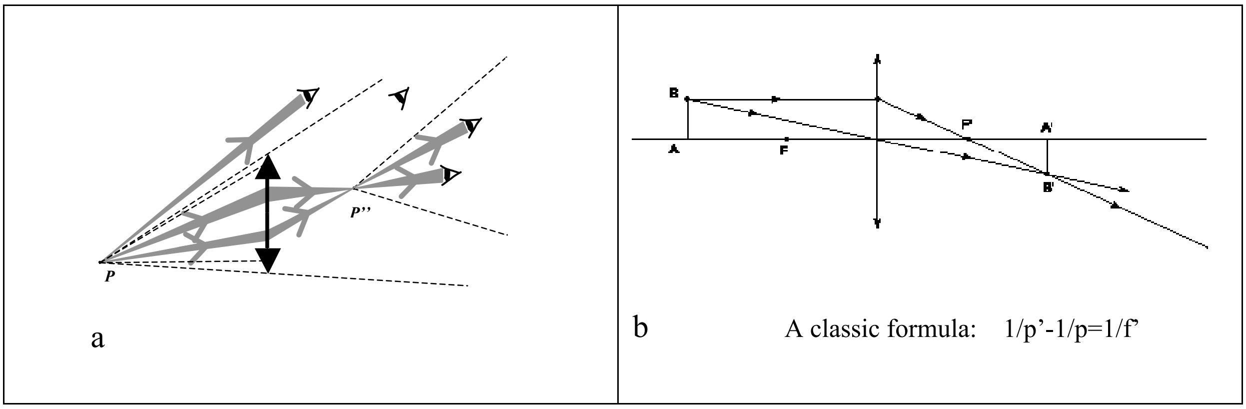

Fig. 4. Different diagrams to represent optical imaging: a (or similar diagrams with an extended object and/or with a screen) stresses the role of the lens, b (or similar diagrams

with an extended object and/or with a screen) classically illustrates how the construction rays help find the position and the size of the image (p, p', f' : algebraic positions of the object, the image, the back focal point; origin: centre of the lens).

An ongoing experiment has yielded some preliminary results that support the above hypothesis[1], i.e. that the diagram in figure 4a may favour students' grasp of optical imaging. This said, even if this is confirmed by further research, it will not mean that a single diagram can change the world of common conceptions in this domain. This example is used here to illustrate how deliberate "spotlighting" of content may bring *precise specification* and *coherence* into our choices of teaching strategies.

Situating the adopted approach

Among the characteristics of the chosen spotlighting, some deserve special attention. Thus, it is well known that it is essential in thermodynamics to differentiate clearly between quasi-static transformations and others. It is less common to specify that analysing the oscillations of a mass suspended from a spring by using the famous relationship $F=-kx$ in fact means considering a quasi-static transformation as well. During the transformation of a spring, all its parts are – so to speak – "warned" at the same time that they should respect a simple law, exactly as the molecules of a gas in quasi-static transformation are said to conform to the relationship $PV = NRT$ at any given time (of course the expressions "warned" and "at the same time" have to be translated into more scientific terms). That kind of comparison may seem useless, but investigations into students' ideas have shown that in both cases this assumed simultaneity may give rise to noticeable difficulties (Rozier & Viennot 1991, Viennot 2001, ch.5). Moreover, in both cases, waves could be propagating in the media (mechanical waves in slinkies, resp. sound), which adds to the usefulness of situating the adopted approach clearly.

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[1] The validation of this idea has had up to now the status of an *a priori* argument. In an ongoing investigation (Viennot, work in progress) the same questions that are classically used to show the presence of the two classic conceptions just recalled – "an image without a lens" and "a hole in the image" to put it briefly – were this time accompanied by diagrams of the recommended type (like the one in fig.4a). They were submitted to one half of a group of trainee teachers (N=21), the other half having the classic version, with a diagram like the one in figure 4b. This difference appears to be associated with a change in the occurrence of notions of the "holes in the image" type and also in the terms used concerning the role of a lens. A group of degree students (N=12) also gave surprisingly few erroneous answers of this type with a test showing the recommended diagram. These groups had previously received the same type of teaching, much less influenced by the official instructions than was wished by the designers of the 1993 syllabus, i.e. probably very conventional. In brief, presented with written tests, some of these relatively advanced students seem to have profited from such simple aid: a favourable diagram, a result which needs to be confirmed with larger samples.

In the same spirit, the difference between "permanent" and "transitory" should always be stressed. This can generate fruitful reflections, specifications and therefore linkages. One can dream of a time when a green house will not be said to receive more energy than it emits without a clear additional claim that this cannot last indefinitely. If such were the case on the Earth, since there is the Sun and an atmosphere, we would not be here to comment on transitorily unbalanced flows of energy.

In the same perspective, the local/global dialectic already illustrated above should consciously be brought to bear. On the basis of recent studies on solid friction (Viennot 2003b) and fluid statics (Besson *et al.* 2000), it has been argued that a mesoscopic level of description can be most useful (Besson & Viennot 2004). This is the case when the analysis of a situation at a macroscopic level turns out to be very frustrating as an explanation, whereas a microscopic analysis is uselessly complicated when envisaging the local aspects. It is not possible to elaborate on this viewpoint in the scope of this paper. But it is worth stressing that it has seldom been exploited in didactic research, although mesoscopic analyses are extensively used in physics, particularly in connection with some topics contemporary research considers highly fruitful. That the mesoscopic approach can also be very useful in teaching is a hypothesis worth exploring further. In particular, it enables teachers to establish a connection between local and global aspects at a reasonable intellectual cost, and therefore to avoid the kind of inconsistencies identified above.

Thinking functional

The end of this paper will centre on functional thinking, as opposed to a purely numerical approach. Again, the aim is to suggest how this can contribute to a unified view of physics among our students.

Returning to our previous example, optical imaging, let us envisage that this time the objective is that pupils learn how to find the sizes and positions of images in Gauss' approximation, for thin lenses or mirrors. The most classically used diagrams are similar to that shown in figure 4b where a no less classic formula is recalled as well. But other formulae, with origins at the focal points, are worth considering. They are very simple: FA.FA'= [-(*lenses) or* + *(mirrors)*] f^2. Moreover, they make it possible to represent the correspondence between object and image positions in elementary optics with only a hyperbola in various positions with respect to the axes – this time, the axes originate at the centre (O) of the lens or at the point (S) of a spherical mirror situated on its axis (fig. 5). With this tool, a number of questions can be easily answered. Whereas on the sole basis of the classic formulae, for instance, it is not easy to predict how the image will be displaced when the object moves along the optical axis in a given direction. Lenses will give one answer, and mirrors, the reverse.

A look at the increasing functions (for lenses, be they converging or not) or the decreasing functions (for mirrors, be they convex or concave) in figure 5 explains these co- or contravariations very easily and in a very *synthetic* way. It is very different from the plethora of diagrams that sometimes fill in the pages of textbooks, showing all the cases that are possible with real or virtual images. Those diagrams are useful too, but they are certainly insufficient to set off the beautiful cohesion of physics. Questions which require an answer in terms of domains of positions – "where should we put this object to get ... a real image, a linear magnification larger than..." – can be answered easily and appropriately on the basis of the hyperbolic curves, and quick comparisons or checks are possible.

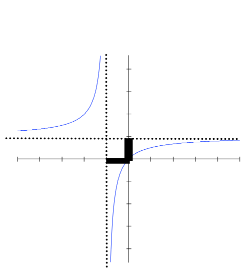
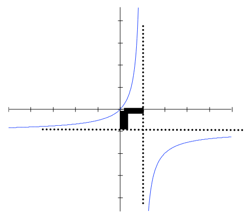
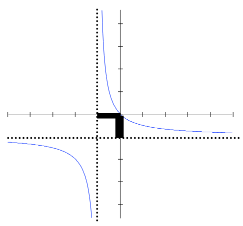
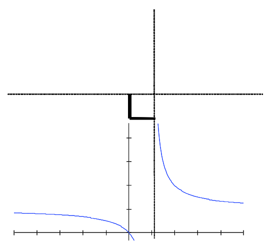
Thin lenses: p'(or OA') is **an increasing function** of p (or OA) (thick segment: focal length)	*Converging lens:* 	*Diverging lens* 
Spherical mirrors p'(or SA') is **a decreasing function** of p (or SA) (thick segment: focal length)	*Concave mirror* 	*Convex mirror* 

Fig. 5. Correspondence between object and image positions for thin lenses and spherical mirrors. In each case, a hyperbola intervenes : FA.FA'= [-(*lenses) or* + *(mirrors)*] f^2, shifted by + or - the focal length along each axis. OA, OA', SA, SA', p, p', FA,FA' are algebraic quantities.

Some might say that none of this is new, which is quite true. Although hyperbolae are surprisingly uncommon in our textbooks on optics, other mathematical formalisms have long been a part of our scientific theories, and their unifying significance has been recognized. The harmonic oscillator model concerns a large range of phenomena, to which we have ascribed a common label. It was one of the great pedagogical ideas of the sixties to adopt this entry in the syllabus; the idea has been reactivated in France at grade 12, for instance (1995 syllabus). Similarly, exponential decay is the subject of recent proposals in the UK (Ogborn *et al.* 2001) and in France (2002). New or not, such suggestions deserve attention and research: to what extent are they successful? Can we facilitate these types of approaches for our students? Not many investigations are available as yet concerning such transversal approaches, although there are some remarkable exceptions (for instance Ogborn 1997), and syllabus planners have probably not given them enough attention. In view of this relative lack of guidance by research, two opposite trends have arisen. One, which is very common at university level, consists in relying on personal or shared conviction alone, and on the beauty of physics. The other, probably more common at secondary level, is to reject this type of endeavour *a priori*, arguing that it is not accessible to students, and that envisaging such an approach is somewhat unrealistic, if not purely elitist. This is why the example chosen below was purposely chosen at a relatively elementary level.

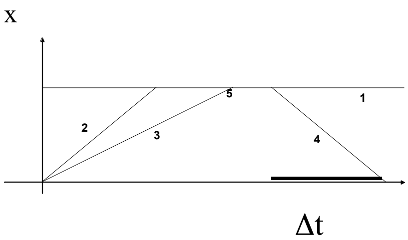
An exercise in style: the extensive power of the relationship d=vt

Let us take as a starting point an in-class activity centring on the image shown in figure 6a . An extraterrestrial humanoid (ET) is shown looking at the Earth with a telescope, and telling his companion that he can see hairy Earthlings trying to make fire. In France, this document has been suggested for use at the national level for grade 10, along with the following question for discussion: What is the distance between the Earth and the ET's planet? It is included in a series of activities entitled "Exploring the universe", concerning the orders of magnitude. Although this was not specifically recommended, the document can be used to (re)activate and extend pupils' knowledge about the relationship x=vt which links travelled distance, time and velocity, the latter quantity being considered constant in time. Mastery of the meaning of the diverse lines in the x/t diagrams shown in figure 6b can be developed. This done, this situation can be analysed, as suggested, in terms of delayed signal and the corresponding number of light-years can be calculated. Then, in order to extend the field of application of this knowledge, a similar example from everyday life can be used with the pupils.

A thunderclap is an especially good example, given that the emitted light and the noise reach a distant observer at different times (fig. 6c). In such a case, light is often said to arrive quasi-instantaneously. This prefix « quasi » poses the question of the order of magnitude of the distance considered with respect to ET's planet, a « very great » distance, as pupils say. This calls for another question, concerning the size of the Earth, seen from the other planet: how is it that its size is so absurdly large ? Then a second-level discussion can be conducted, as to why the illustrator chose to make the Earth so big. An investigation conducted with various groups (14 interviews in the first university year, questionnaires to 14 degree students and to 62 students at grade 12, ongoing work Feller & Viennot) shows that students can participate profitably in such a discussion, rather than considering this deeply inconsistent document docilely.

The next step can be to discuss the echo phenomenon, on the basis of similar graphs (fig. 6d), for instance in relation to the way bats detect obstacles. A further step is to consider a receptor or an emitter moving with respect to the considered frame of reference. Doppler effect is then accessible by way of a graphical approach of the same type (fig. 6e). It is even possible to link Römer's discovery to Doppler effect (Viennot & Leroy 2004). Indeed, the luminous signal emitted from the Jupiter's system at each outset of a satellite, say Io, is periodic (Io : T=42,5h) and received by a receptor, someone on the Earth, which moves with respect to Jupiter. When this movement results in a stationary distance between the two planets, there is no Doppler effect and the reception period is identical to the period of emission. In contrast, when the relative radial velocity is the greatest, at two points of the Earth's orbit which are equidistant from Jupiter, there is a maximum shift in the period of reception. This is especially easy to understand with the graphs shown in figure 6f. It is also possible to come back to the core of Römer's discovery, i.e. that the value of the velocity of light is finite. If this were not the case, the incline lines corresponding to the signal's trajectory would be vertical and there would be no shift in the reception times relative to the emission times, whatever the motion of the receptor with respect to the source. Of course, it is possible to pursue this vein further. The world lines of Einsteinian relativity are an obvious extension of this type of analysis. But the stress here is on what is possible at a relatively elementary level. The conceptual path presented here focuses on the potentialities of a very commonplace relationship, the range of application of which goes far beyond trains, cars, or pucks on air tracks.

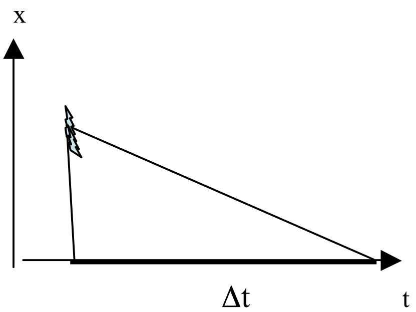
a A document proposed for grade 10: see caption



Delayed signals

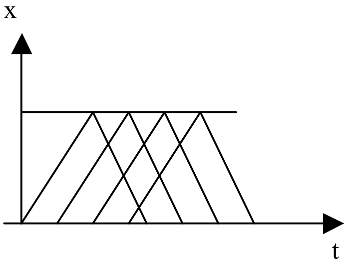
Various cases and corresponding graphs. 2 and 3: from the origin (3: slower), 4: reverse direction (as in a); 5: a meeting with a "motionless" object.

b



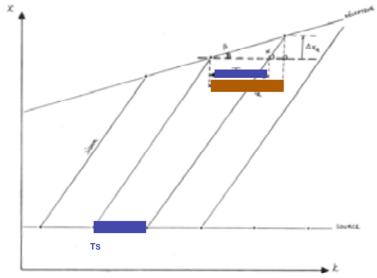
A thunderclap: light and sound are received at different times

c



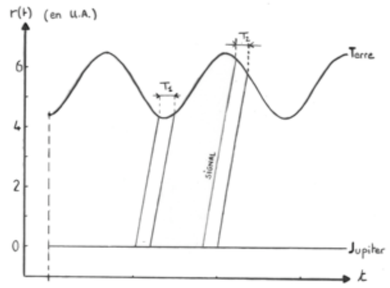
Bats using echoes: a series of emitted signals are sent back by an obstacle

d



Doppler effect: a receptor moving away from the source: the period of reception is different from the period of emission.

e



A periodic signal from Jupiter (outsets of IO) received on the Earth, which is at a variable distance from Jupiter throughout the year

f

Fig.6. Various situations that can be analysed with the same type of graphic. Bubbles in a): - "I can see Earthlings, they are hairy and they are trying to make fire" – "I wonder how far the Earth is from here?"

A sequence based on this conceptual linkage was experimented with degree students (n=14). One of the comments collected was "we felt autonomous, it was pleasant". Asked to elaborate upon this impression, given that autonomy was not an explicit goal in this very guided sequence, the student added: "We had the means to think about many phenomena, it was accessible, it was profitable".

Recapitulation and concluding remarks

This paper envisages a few possible parameters regarding our choices in physics teaching. The question that orientates this discussion is whether it is possible to conciliate two goals : raising students' satisfaction in their work on physics and introducing them to the unifying power of this science. The real challenge for research, now, is to go beyond mere claims of conviction and to provide usable experimental facts to inform this discussion. Some evidence is provided here that our common teaching practices often verge on incoherence and strongly encourage a fragmented view of physics. It is also to be noted that the analysis proposed here largely bears on « critical details » of practice, i.e. apparently minor aspects of teaching that may eventually have important effects (Viennot 2003a, b). This does not mean that students react immediately to the inconsistencies denounced here, and that they consciously reject physics on this basis. Even if a minority of them do so, it is very likely that the others just feel vaguely in doubt, at most. Are we not always lamenting that they lack critical sense ?

This debate should be viewed as positive. What if we teachers try to show explicitly that some aspects of physics are problematic and that some apparent contradictions can be overcome beautifully? What if we stress the splendid unifying power of *even simple* theoretical tools? These days, when it is universally recommended that we emphasize the difficulties of our ancestors in their efforts to develop science, why not highlight the quality of the results obtained as well? This « quality », I suggest, is not only to be found in spectacular features of science, which may cause intense, but short-lived and fragmented amazement.

This viewpoint is not novel. Many scientists consulted to design curricula or to write textbooks have defended it. But a real effort of adaptation still needs to be made. This endeavour cannot rely only on inspiration or on the intrinsic beauty of physics. It should be conducted at low academic levels, and at the micro-level of practice. The price to pay, with such an ambitious teaching goal, is a thorough examination of our teaching strategies, and an acceptance of this *a priori* obvious but still dramatically disregarded idea: we have to evaluate what we propose; research is needed.

The results presently available show that in some content domains, taking these requisites seriously leads to appreciable results. We now have to extend our efforts in two directions: research on the one hand, and better interfacing between research and practice on the other. The second point is probably the more challenging, given the variety of reasons that induce us, teachers, not to change our views and teaching strategies.

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CONTRIBUTED PAPERS

NOT CHAPTERS BUT PHENOMENOLOGICAL SIMILARITIES AND UNIFIED CONCEPTUAL EXPLANATIONS

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In the traditional organization of Physics teaching the various kinds of changes of objects in interaction with an environment are treated in separate chapters with no consideration of differences and similarities. Starting with a discussion of the models used in Physics the paper describes such differences and similarities. An example of the similarity in the time behaviour of different processes is then given suggesting a unification at the descriptive level. The discussion of a possible unification at the explicative level (with energy and entropy as cognitive organizers) concludes the paper.

Introduction

It may be asserted that Physics in general is concerned with the analysis of the changes of objects in relation with their environment. In the traditional organization of physics teaching the various kinds of changes are treated in separate chapters with no consideration for similarities in their description. We thus have that changes in the spatial position belong to the chapter on "Mechanics" with an extended discussion of the various kinds of motion of localized objects in the subchapter named "kinematics". The changes in thermal properties are only roughly sketched in the chapters on thermology before entering the field of thermostatic and with no follow up in the thermodynamics of processes which has been developed in the last century.

The changes in the electrical and magnetic properties are discussed in other chapters again starting, in general, from the analysis of the equilibrium situations to be followed by the consideration of changes in time. It is then difficult for a student to focus on the differences and similarities in the phenomenological behaviour. Such a focus may be obtained by the explicit treatment of such differences and similarities which implies the unified considerations of the time changes in space, in temperature and in the electrical properties.

In order to focus the differences we will start with a discussion on the models used in Physics to describe a real object (see section 2) followed by a discussion on the models of interaction (section 3). The similarities in the phenomenological behaviour are then illustrated (section 4).

The last section (section 5) focuses on the cognitive organizers for the explanation of the phenomena.

The objects of Physics and their models

To our perception an object is a bunch of matter extended in a confined space either by the external surface of a solid or by the boundaries defined by the containers of fluids. It thus has an interior characterized by properties like the quantity of matter and the extension in space.
The study of Physics substitutes the real objects of our daily life with some model objects according to the properties and behaviours to be described and explained. As the model must have some correspondence with reality it would seem that the most general model is that of a macro object with simplified geometrical boundaries but with an interior that may change when interacting with the environment: that is a Thermodynamic System. However the characterization of the interior by suitable variables was not an easy task in the development of scientific knowledge while the behaviour of some phenomenon, in particular the movement of solid objects, could be described assuming that the changes in the inside were negligible.

Thus the models for motion, implicitly assuming the invariance of the interior of the object, were built with the image of a perfectly symmetrical object – the ball of utopio as Ridley defines it (Ridley 1994) – which is reduced to a "material point" when the interior is completely neglected. The interior is taken into account in the continuum model of application in the study of transport processes. Also this model has a limiting case when the extension of the interior is very large, say infinite. In this extension motion may be generated and the sinusoidal wave becomes a fundamental element, complementary to material point, for the description of the global properties of the object. In contrast to the continuum model, in which the macroscopic object is considered as constituted by material elements with the same properties of the bulk object, one has the "particle model" in which the microscopic elements that are assumed to constitute the object are given a partial set of properties to describe the phenomenological behaviour by statistical tools. An example is the kinetic model of a gas where the constituent atoms are characterized by mass, momentum and energy. We note that, in any model, the object or its constituent elements are characterized by properties related to the spatial extension, the so called "extensive variables". In order to apply the models to the study of phenomena the possible reasons for change and their models must be considered.

Interactions and changes

The interaction with the environment may induce changes in a macroscopic object. Therefore, in order to obtain equilibrium situations some constraints must be imposed to screen the interaction.

The removal of a constraint then produces a dynamical situation of change. The same may be obtained by some action of an observer-experimentalist. From the point of view of the object a change in the property X may be described by

[rate of increase of X]=[entering rate of X]-[leaving rate of X]+[rate of production of X inside]
(equation of continuity)

The change is correlated to the difference in a variable Y (conjugate to X) between the object and the environment (intensive variables). The relation between ΔY and the flux of X (into or out) of the object gives then the equation of change (Bird, 2002)

[flux of X] + [change in the flux in time] α ΔY

$\Downarrow$

= 0 in the stationary case.

It should be noted that in this frame the interaction is modelled in the two aspects:

- an exchange of extensive variables as expressed by the continuity equation;
- a difference in the intensive variables as expressed by the equation of change.

This approach may then open the way to the description of interaction in modern physics as the exchange of particles and fields.

An example of similarities in the phenomenological behaviour

For an object in a constrained equilibrium situation the triggering of a change, by the removal of a constraint, towards a new equilibrium situation has the same behaviour for:

- an object in the gravitational field, on a curved constraint,
- a fluid in an U tube with an initial level difference.

The behaviour is of an oscillatory damped motion characterized by a period T and a time constant τ and described graphically as $\Delta h=\Delta h(t)$ (see fig.1) and analytically by:

$$\Delta h = \Delta h_0 \, e^{-t/\tau} \cos(\omega t+\varphi)$$

Analogous behaviour is observed in the discharge of a condenser, represented by the voltage V, in an RL circuit where:

$$\Delta V = \Delta V_0 \, e^{-t/\tau} \cos(\omega t+\varphi)$$

Again an analogous behaviour is observed in the process toward thermal equilibrium by conduction, represented by the temperature T, where, however, the oscillatory part is seldom observed and

$$\Delta T = \Delta T_0 \, e^{-t/\tau}$$

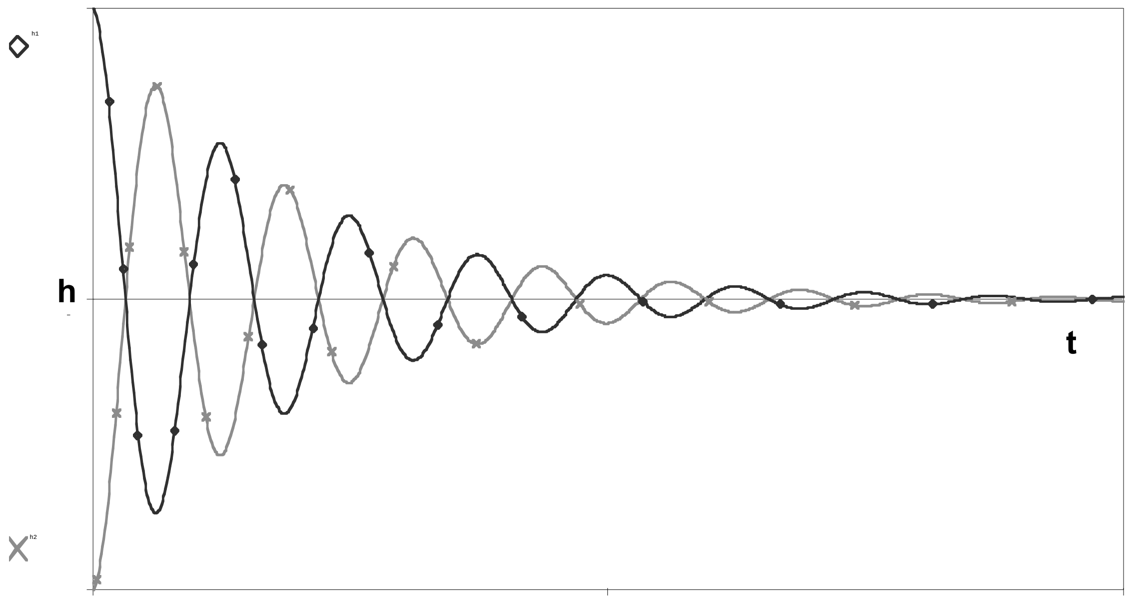

Fig.1 – The graphical description of the phenomenon

In Table 1 we show the synthesis of the different cases.

Table 1: Synthesis of the phenomena

Phenomenon	Intensive variable	Equilibrium Condition	Equation of change
Flow of liquids in two connected vessels	h	$\Delta h = 0$	$\Delta h=\Delta h_0 e^{-t/\tau} \cos \omega t$
Process toward thermal equilibrium	T	$\Delta T = 0$	$\Delta T=\Delta T_0 e^{-t/\tau}$
Discharge of a condenser	V	$\Delta V = 0$	$\Delta V=\Delta V_0 e^{-t/\tau} \cos \omega t$

h = height, T = temperature, V = voltage

It must be noted that the approach starts from the consideration of few basic concepts, namely equilibrium and change, to proceed to the introduction of the variables needed for the description of different phenomena Thus a qualitative analysis of the graphical representation of the changes permits the discussion of two characteristics of any process, namely the coexistence of a “conservative” aspect (the oscillations) with a “dissipative” aspect (the damping).

Moreover the same analysis permits the introduction of two kinds of variables for the description of a system: the extensive and the intensive ones.

It can be shown that a difference in the intensive variables Y_i (Δh, ΔV, ΔT) generates a flow of an extensive one X_i (m, q, Q) with the relation:

$$\Delta Y_i = a\Phi\ (Xi) + b\ \frac{d\Phi(X_i)}{dt}$$

The first term being related to the dissipative aspect of the process and the second to the conservative aspect. The extensive variables are obvious in the case of the flow of liquids (the difference in height produces a mass current) and for the electric case (the difference in the potential produces an electrical current). For the thermal case it is intuitively obvious that a temperature difference gives rise to an heat flow. However there is a problem in defining the extensive variable connected with the variable heat. The problem may be also traced in the history of Thermodynamics with the dispute about the substantial character of heat. The problem is also correlated with the non conservation of heat which gives a production term in the continuity equation. At this stage it is reasonable to accept the description with a “heat” variable with the explicitation of the problems in its definition as a system variable.

It may be noted that the mathematical language needed for the formal description of the phenomena also underlines the unification while implying simple mathematical tools (the exponential, the trigonometric functions, the first derivative, proportionality relations, the use of Cartesian graph). Therefore, while the approach is not aimed (in principle) to a specific level of schooling, it may be used at the university, in teacher training (where it has been experimented) and in the secondary school (Sperandeo 2004).

In an analogous way one may introduce the kinematics of the waves propagating in an extended macroscopic object as the result of a disturbance from the equilibrium situation either as an impulse (which introduces a rapid change in an intensive variable ΔY_i) or as a periodic disturbance $\Delta Y_i = \Delta Y_{i0} \sin(\omega t)$.

Intensive and extensive variables are also correlated in the description of the equilibrium properties of different extended systems. The "equations of state" should not be restricted to the perfect gas relation but should include other relations (usually presented in textbooks as the relation between an external action and an internal reaction) like the thermal dilatation, the Hooke relation between the length and the internal tension of an elastic material, the relation between the polarization of a dielectric material and the electric field, the relation between the magnetization and the magnetic field for a material with magnetic properties. It can be thus suggested that a thermal effect is connected with all kinds of processes.

The cognitive organizers for an explanation

The unification of the description of phenomena traditionally presented in different chapters (mechanics, thermodynamic, electromagnetism) suggests the need of the search of cognitive organizers for the explanation applicable in all cases. Therefore energy should be chosen as a primitive concept to be introduced in an intuitive way also for its symbolic expression (Bunge, 2000).

This may be done in the following way having as a reference the phenomenological behaviour of fig.1: in the initial static situation obtained by the action of a constraint (a support for motion, an adiabatic wall in the thermal case, the opening of the circuit in the electrical case) that screens the interaction due to the difference in the variable Y, we assume that the object has the potentiality for a change. This potentiality depends on the value of Y in the constrained situation and on the X property of the object. The simplest definition for this new variable describing the potentiality is given by

$$E_p = a\,X \cdot Y$$

Call it "potential energy".

The removal of the constraint activates the interaction and the object will lose part of the potential energy while acquiring a generalized velocity (or rate of change).
One can correlate the velocity with a change in energy - call it kinetic energy – using the expression

$$E_k = bX^2$$

which is, again, the simplest expression that satisfies the symmetry requirements of the oscillatory case ($E_K = 0$ if $X^2=0$).
The consideration of the case of negligible damping then leads to the conservation relation

$$E_p + E_K = \text{constant}$$

In the presence of damping a new energy is needed to preserve a general conservation law

$$E_p + E_K + U = \text{constant}$$

Again, while there are no problems in accepting the definition for the mechanical and the electric case, the thermal case poses a problem. One may then take here the issue of the definition of the extensive variables internal energy and entropy though the presentation of the first and second law of Thermodynamics. In fact the thermal case is described by the damping without oscillations where in the final state the initial potential energy has been totally changed in the internal energy of the system.

The second law then tells us that the extensive variable accompanying the energy transfer is the entropy, therefore the heat flow is the entropy flow (Hermann 1994). The entropy production may also be discussed explicating its importance in all the phenomena where damping (dissipation) is present. In this frame the interaction is described by the intensive variables, or fields, and the exchange of extensive variables. Of course the concept of force may be then introduced as a derived concept by its relation with the potential energy

$$F = \frac{dU_p}{dr} = \frac{dU_p}{dY} gradY$$

Note that here the name "force" is restricted to the conservative forces while the damping due to friction is attributed to entropy.

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PROMOTING A COMMON SNUC LANGUAGE IN THE NATURAL AND MATHEMATICAL SCIENCES

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When we teach the natural and mathematical sciences, we use three ‘languages’ to do so: Scientific English, Mathematics and the language of symbols, notation, units and conventions (SNUC). In a typical secondary school, university or college setting, a student will at the same time be exposed to a number of disciplines that utilise these languages in different ways. Temperature is used as an example to illustrate the difficulties that students are exposed to when learning. Finally, some resources that could be used to promote a common SNUC language are indicated.

Introduction: The languages

When we teach and learn Physics or any of the other natural or mathematical sciences, we utilise three common ‘languages’. These languages are depicted in figure 1. The first one is Scientific English, the second the language of Mathematics and the third that of symbols, notation, units and conventions (SNUC).

Natural and mathematical scientists like physicists, chemists, biologists, geographers, mathematicians and statisticians study the same natural world but focus on different aspects thereof. They utilise these ‘languages’ in different ways to communicate within their field of study as well as to others outside that field. The focus in this paper is on the third language, namely SNUC.

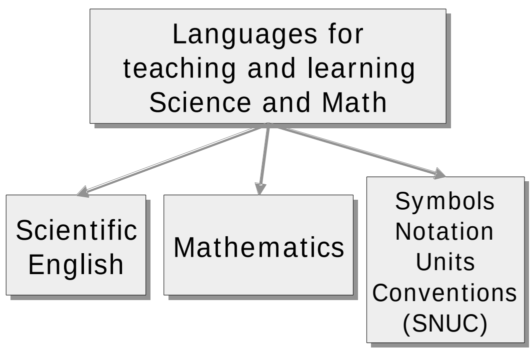

Figure 1. The languages of the natural and mathematical sciences

The setting

In a typical secondary school or undergraduate university or college setting, students could be exposed to anything up to five or six of these disciplines during the same academic year. The younger they are, the higher the probability of having to study the largest number of these disciplines at the same time.

The challenges/difficulties for students

Students have to cope with all these disciplines and in all three languages at the same time. Mathematics and Statistics teachers and lecturers more and more use contexts from the natural sciences and engineering to teach the mathematical disciplines. One example is the study of motion in Physics that is used as a context in Mathematics to learn about calculus. So there is a large common subset of the natural science disciplines as well as the mathematical ones where students hear and learn about the same things. That implies that there is also a part of SNUC that constitutes a common set for all the disciplines mentioned above. If one takes a careful look at the study material for these disciplines, whether it is textbooks, laboratory manuals, software, videos or just classroom notes, it is striking to see the vast differences in approach that authors, lecturers and teachers follow when 'writing' for there prospective audiences. It is acknowledged that students need to be exposed to a variety of styles and approaches to science and mathematics, but when it comes to SNUC, it seems that SNUC complicates, rather than simplify the learning process.

The example: temperature

Temperature, or to be more specific thermodynamic temperature is one of the seven base quantities in the *Système International* (SI). The quantity of temperature is a good example to illustrate some of the SNUC difficulties that learners need to overcome when they encounter the concept temperature; specifically in physics, chemistry, biology, geography, mathematics and statistics (figure 2). Temperature is conceptually demanding. And although the laws and phenomena of nature hold for any units, as we believe and as we want students to conceptualise it, matters about learning this get complicated when students have to deal with SNUC. The examples that follow are all taken from textbooks currently or recently being used at the University of South Africa.

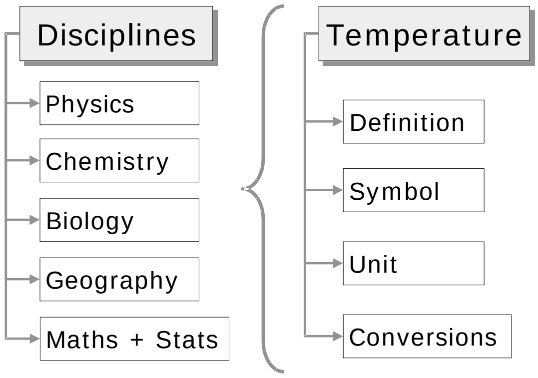

Figure 2. Temperature used as example in various disciplines

To start with, let us consider the 'definition' or the description given of temperature. Table 1 provides the details. Clearly there is no consistent description emerging. A student writing simultaneous examinations in Physics, Chemistry and say Geography might experience great difficulties, considering the variety of answers on a concept like temperature that might be expected of him/her by lecturers teaching the various subjects.

Table 1: Definition/Description of temperature

Discipline	Reference	Definition/Description of temperature
Physics	Halliday *et al.* 2001	Temperature is one of seven SI base quantities. Every body has a property called temperature. When two bodies are in thermal equilibrium, their temperatures are equal.
Chemistry	Zumdahl & Zumdahl 2000	Temperature is an indicator of the average kinetic energy of particles.
Biology	Campbell 1996	Temperature measures the intensity of heat due to the average kinetic energy of molecules.
Geography	Strahler & Strahler 1994	Temperature is a measure of the level of sensible heat of matter, whether it is gaseous, liquid or solid.
Mathematics	Bohlman &Singleton 1997	None given.

The second complicating factor is the use of symbols. Here we have to be mindful of the quantity symbol as well as the unit and the unit symbol. Table 2 provides a summary of the variety of symbols used by the same authors referenced in Table 1. Unlike for the other base quantities, it seems that authors use various quantity symbols for temperature depending on the units under consideration.

Table 2. Quantity and unit symbols (Notice the use of roman and italic fonts)

Discipline	Quantity symbol			Unit symbol		
	Kelvin	Celsius	Fahrenheit	Kelvin	Celsius	Fahrenheit
Physics	T	T_C	T_F	K	°C for T_C C° for ΔT_C	°F for T_F F° for ΔT_F
Chemistry	T_K	T_C and $°C$	T_F and $°F$	K	°C	°F
Biology	-	$°C$	$°F$	°K	°C	°F
Geography	-	C	F	K	°C	°F
Math	-	C	F	-	$°C$	$°F$

Considering that we have the SI, it is probably not surprising that table 2 presents a more coherent approach than the descriptions in table 1. But a challenge for students is to cope with the fact that some lecturers mix the application of quantity and unit symbols. It is seen frequently in textbooks that authors use unit symbols in stead of quantity symbols to set up equations. It leads to a situation where the variables in an equation are represented with the same symbols as the units of the quantities. Table 3 shows examples of temperature conversions as indicated in the references mentioned in table 1.

In the Chemistry textbook for example, the conversions between degrees Celsius and Kelvin and degrees Celsius and degrees Fahrenheit are given in terms of quantity symbols using *T'*s with subscripts as well as in terms of the unit symbols. The next difficulty for a student is to remember where to put the little degree circle '° '. There is no consistent use when carefully scanning through tables 2 and 3.

Table 3: Conversion of temperature units (same references as in table 1)

Discipline	Celsius _ Kelvin	Celsius _ Fahrenheit
Physics	$T_C = T - 273.15°$	$T_F = \frac{9}{5} T_C + 32°$
Chemistry	$T_C = T_K - 273.15$ $K = °C + 273$	$T_F = T_C \times \dfrac{9°\mathrm{F}}{5°\mathrm{C}} + 32°\mathrm{F}$ $°C = \frac{5}{9}(°F - 32)$
Biology	none	$°C = \frac{5}{9}(°F - 32)$

Geography	none	$C = \frac{5}{9}(F - 32°)$
Math	none	$F = 1{,}8C + 32$

In addition to the content shown in table 3, the Physics textbook introduces another convention when emphasising the difference between absolute temperature T and temperature differences or temperature ranges ΔT. In the first case the symbol used for degrees Celsius is °C and for the latter C°. This facilitates the difference between $T = 10°\mathrm{C} = 50°\mathrm{F}$ and $\Delta T = 10°\mathrm{C} = 18°\mathrm{F}$. So the notation used for the second expression is $\Delta T = 10\,\mathrm{C}° = 18\,\mathrm{F}°$. The notation with the degree circle after the letter C or F is also found in the Geography textbook mentioned in Table.1. Contrary to the Chemistry case, it is used for the quantity symbol not for the unit symbol. An example is where the mean annual temperature, denoted by $C°$ and measured in °C is given as a function of the mean annual precipitation P measured in cm. The following is an expression taken from the textbook $P = C° + 7$ with P in cm and $C°$ in °C. And finally there are also some textbook authors that avoid showing conversion equations. An example is another Geography textbook that only supplies a conversion scale where one reads off corresponding numerical values in °C and °F (Bergman and Renwick, 1999).

A common SNUC language

Although forums have been created internationally where multi-disciplinary issues are dealt with, there are still not many opportunities where the lecturers and teachers of natural science disciplines could discuss or agree on issues like SNUC. Mathematicians and Statisticians are even more remote from debates in Science, although they use Science contexts. From the temperature example above it seems desirable to promote a common SNUC language. Not only will it remove ambiguities and uncertainties, but more importantly it will remove unnecessary hurdles for students when they try to learn about the natural and mathematical sciences.

The resources

A wealth of resources and channels exist that could be used to promote a common SNUC language across disciplines. When talking to colleagues in Mathematics and Statistics especially, it seems that they are not aware of these resources. Examples of these resources are (web references are given as part of the list at the end of the paper):

1. SNUC guidelines of organisations like International Union of Pure and Applied Physics (IUPAP, 2004), International Union of Pure and Applied Chemistry (IUPAC, 2004),

International Union of Biochemistry and Molecular Biology (IUBMB, 2004)) and International Union of Geological Sciences (IUGS, 2004)

2. International Organization for Standardization (ISO) publications (ISO, 1998)
3. International Council for Science (ICSU, 2004): Committee on Data for Science and Technology (CODATA, 2004)
4. National Institute of Science and Technology (NIST, 2004) documents
5. The constants and equations pages (TCAEP, 2004), sponsored by the Institute of Physics (IOP)
6. CRC Handbook of Chemistry and Physics (Lide, 2003)

There is already a lot of common ground when one considers for example an IUPAC publication like 'Quantities, Units and Symbols in Physical Chemistry' (Mills et al. 1993) and the CRC Handbook of Chemistry and Physics (Lide, 2003). In this regard the ISO publication 'SI Guide: International System of Units' (1998) is a very useful booklet that provides a condensed overview of the principles of the SI, units, printing rules for quantity and unit symbols, etc. But there seems to be scope for further debate and agreement. The ISO booklet for example indicates thermodynamic temperature with a capital T, but Celsius temperature with a small letter t as shown in table 4. A small letter t is also used to indicate time. How would one then print a rate of change of temperature when the temperature is given in degrees Celsius? If we use the ISO guidelines, it would be $\Delta t/\Delta t$ (?). Surely $\Delta T/\Delta t$ or $\Delta T_C /\Delta t$ would be a better choice.

Table 4: Quantity and unit symbols prescribed by ISO

Temperature	Kelvin	Celsius	Fahrenheit
Quantity symbol	T	t	t_F
Unit symbol	K	°C	°F

If we briefly consider the way of printing and dealing with temperature conversions prescribed by ISO and the CRC Handbook of Chemistry and Physics (table 5), we notice (compare with table 3) that there is none of the textbook authors listed in table 1 that shows conversions the recommended way.

Table 5: Temperature conversions prescribed by ISO and the CRC Handbook

Conversions	K _ °C	°C _ °F
ISO	$t = T - 273{,}15$	$\frac{t_F}{°\mathrm{F}} = \frac{9}{5}\frac{t}{°\mathrm{C}} + 32$

CRC Handbook	$\frac{T}{\text{K}} = \frac{t}{°\text{C}} + 273.15$	$\frac{t_F}{°\text{F}} = \frac{9}{5}\frac{t}{°\text{C}} + 32$

A final note on conventions: Table 5 also shows the accepted use of both the decimal point and decimal comma. Could we agree on using only one? Why should a student punch a decimal point on his/her pocket calculator or computer when entering decimal numbers for a calculation and then switch to a decimal comma when he/she wants to write down the decimal answer?

Conclusions and recommendations

We rarely explicitly teach about SNUC. The differences between quantity and unit symbols and the way it is written or printed are seldom emphasised. Our science and mathematics training programmes and especially the teacher training programmes do not provide for interdisciplinary discussion about common issues, like SNUC. There seems to be scope for broader agreement about SNUC. It could be promoted via formal contact between the organisations already mentioned. But it could also be promoted via a less formal route within and amongst schools, colleges and universities where all of us are involved with the training of our future scientists and teachers.

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RESEARCH ON THE CONCEPTUAL ORGANIZATION OF PHYSICS' CURRICULUM AND STANDARDS

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We outline the most significant features of research conducted in the last years within three *National Research Projects*. First, we will discuss some shared, strategic research-choices and guidelines, validated by research results. Then, by a bottom-up approach, we will focus our attention on problems related to long-term Physics' *curricular planning* and to a correlated *schematic Standards' definition.* We propose to structure the *phenomenological side* of the curriculum according to *eight content areas*. Some structuring concepts and processes are made explicit as teaching/learning *strategies* (corresponding to *ways of thinking*, *ways to look-at*, *modes of action*, *ways to talk about*, etc). Such "universal categorisation tools" should be introduced from the very beginning of the *talking-about* and of the *acting-on* aspects of the physical world, and progressively explicated, formalised, reciprocally structured. Several levels of *giving shape to* (formalising) physical phenomena should thus become gradually accessible, keeping in mind that all the ones up to a given level are actually necessary for meaningful understanding.

Introduction

Teaching represents a purposeful, individually-oriented, socially steered activity aimed at learning with a population-level validation. In our society, however, teaching-learning results are often deceiving ones, despite efforts invested in ad-hoc research carried out in the last several decades. In particular, as for Physics (and Mathematics) learning, two crucial ingredients are concerned - *understanding and motivation*: elements that are more and more at stake all over the world among today's students. In fact, over the years it has been clearly documented that too often students do not draw out of their school-time enough understanding to trigger their personal motivations (life-worth); while creative understanding is hindered by lack of motivation. Therefore, a strong need is felt throughout the scientific community to define new curricula and new standards for school-mediated understanding, hoping to trigger in this way real innovation processes.

The ideas outlined hereafter have been developing within research groups, active in various Italian Universities, working on the teaching of Physics from kindergarten to first year university. The research has been framed in the last years by three *National Research Projects*; its results are being mostly utilised in the design and experimentation of instructional paths for students and teachers, on central themes regarding all levels of basic Physics Education.

Cogent evidence from our research

In the following Table I we schematically outline some *shared guidelines and strategic choices* which have been driving our research, and which have been corroborated and validated by the results of research itself: we think now that any successful innovation could not ignore them, and in this spirit we intend to propose them to wider discussion.

TABLE I
Guidelines and strategic choices for effective innovation:
necessary (not sufficient) ingredients

i)	Long-term, variational action at basic cognitive and experience levels, aiming at optimising the actual dynamics of cultural mediation within the classroom rather than to analyse students' (or teachers') misbehaviours: students' and teachers' comprehension difficulties should be valued by relating them to the standard structures of the discipline.
ii)	Accordingly, readiness to constructively face and work-out even radical discipline's conceptual and operational reorganisations, able to trigger and to support "resonant" understanding dynamics, then to improve final-competence achievements.
iii)	Enforcing of a long-term (longitudinal) continuity across school levels, and of a transversal co-ordination across disciplines (mainly in Physics, Mathematics, Language, Technology and other Sciences), seen as necessary supports to the complex development of any conceptualisation bridging the gap from "natural" to "scientific" thinking.
iv)	Enforcing of a strict and explicit coherence, across all age intervals, of the models and theories gradually proposed in Physics teaching, on one side with real-life, diffused, widespread "experience", on the other side with laboratory ad-hoc "experiments".
v)	Awareness, in teaching as well as in learning, of the crucial roles played at all age levels by a coherent "phenomenological-vs.-modelling" approach: in describing the physical phenomena as in defining the physical concepts as in correlating them by "theory" links.
vi)	Awareness of the crucial roles played at all age levels by "formal" (mathematical) aspects, seen not as "representing" but rather as directly "structuring" the physical re-constructions of the world, at resonance with inter-contextual space-time-causality cognitive strategies. Accordingly, systematic and constructive interference between phenomenological and formal learning and meta-cognitive control, throughout the conceptual construction.
vii)	Confidence in the crucial help potentially available at all age levels by information-technology supports - from online transduction to data representation and fitting, from formal handling to variational modelling: provided the informatic medium is used in explicit (meta-cognitively controlled) resonance with the dynamics of understanding.
viii)	Systematic "early start", in both absolute and relative time scales, fostering physical understanding according to evolving formal and experience formats and/or models
ix)	Critical confrontation, in planning teaching and in evaluating its results, with on-the-field research and innovation results, and with the available models of cognitive dynamics: such a confrontation should be made explicit, and accessible, to teachers.

Our "in progress" proposal

Following a bottom-up approach allowed by our significant research results in several specific areas of physics teaching, we have recently decided to focus our attention on a long-term, self-consistent Physics Curricular Planning and on a correlated, schematic definition of Standards for learning and understanding in Physics. Both these aspects are seen as necessary boundary conditions, and as starting points, within which the crucially "creative" mediation activity of teachers should take shape and evolve. (Our experience shows in fact that a significant professional development of teachers is essential to launch and to support any real improvement of the whole teaching system). Here we will concentrate our attention on the curriculum-planning aspects.

Meaningful-and-effective curricular planning in Physics (in Sciences) represents today a very hard endeavour: basically, one has to overcome the deep gaps dividing cultural complexities and social needs, teaching effectiveness and allowed times, natural know-how and scientific know-that, etc. In our thorough exploration of the curricular projects being currently developed, we found ourselves quite in tuning with many of the general planning criteria extensively explicited by the N.S.F. proposal (www.nap.edu/readingroom/books/nses); as we found very useful many suggestions coming from structured Projects such as 'Advancing Physics' (http://advancingphysics.iop.org), 'Karlsruhe Physics' (www.iop.org/EJ/abstract/0143-0807/21/1/308), and others.

We felt however that, to actually tune the general teaching strategies outlined in Table I to a significant set of physical contents and teaching practices, a further effort was to be made: one to make as explicit as possible the criteria by which definite teaching/learning paths are chosen at curricular level, and then articulated across ages and competence objectives. We think in fact that this is the only way by which a curricular proposal can, on one side, support the complex interplay between teachers' autonomies and socio-cultural concerns; on the other side, to foster optimising variations (by teachers-experts "local" cooperation, eventually supported by web interactions) which are badly needed to ensure survival and development of the proposed innovation.

To make the discussion easier, we now proceed to directly and schematically list, in the following Tables, some of the specific criteria shaping our curricular planning, grouped according to different *points of view* which we feel should necessarily converge into any definite proposal of physics curriculum. (Obviously a fine-grain analysis, in some respects the only critical one, is necessarily left out of this paper for space-time constraints).

TABLE II

Criteria to be enforced from the point of view of the (culturally drawn) "physical object"

The curricular texture must exhibit:

- a phenomenology-based content structure, to be gradually and explicitly rearranged throughout the years to fit more and more broad, profound and efficient interpretations (models and theories);
- a meaningful reciprocal rooting, across ages and competence levels, of school learning of Physics vs. acting out Physics in every day life: this in accordance with a substantial continuity to be activated at the interface between the perceptual channels and the culturally defined, basic structures of classical physics;
- a meaningful, strategically crucial, explicit rearrangement within conceptual structures, to be activated whenever phenomenologically-based networks of models clash into one another under the request of broader and more coherent interpretations: this occurs already at very early levels (as in friction, overlapping mechanical and thermal ideas), but it is critical at the relatively advanced ones where the ideas in modern Physics have to be introduced and activated in selected contexts, then generalized by formal devices;
- a meaningful correlation between the evolution of specific ideas in Physics and their impact or feedback in relation to contiguous scientific field, such as Chemistry or Biology; a typical teaching-learning exploitation of this constructive interference across disciplines can be activated by the definition and the organisation of Physics' and Mathematics' concepts.

TABLE II.A
Longitudinal organisation of the Physics curriculum according to parallel content-areas

The "phenomenological" part of the curriculum is structured according to the following areas, to be progressively articulated and correlated to each other along the years:

A1) Mechanics of finite systems;	A2) Thermal phenomena;	A3) Light phenomena;
A4) Electric and magnetic phenomena	A5) Oscillations and waves;	A6) Matter and fields;
A7) Earth and Universe;	A8) Instruments and tools, engines and apparatuses.	

The last four areas are "transversal" ones: in fact A5 involves/correlates mechanical, acoustical, hydrodynamic, optical, electromagnetic phenomena; A6, A7, A8 involve, at all levels and in suitable reorganisations, elements of the first five areas.

TABLE II.B
Criteria to be enforced from the point of view of the (culturally shaped) "knowing subject"

A variety of cognitive strategies are crucial to physics conceptualisation, and active since very early ages in any format of talking-about and acting-about physics' facts: rooted in basic cognitive dynamics, they become progressively differentiated and reciprocally structured to fit in a resonant way different contexts, according to different formalisation criteria and tools. Such essential strategies (or "unifying concepts) correspond to "ways of thinking", "ways to look-at", "criteria of action", "ways to talk about", "modalities or representation", etc): they should be clarified, as woven through the contents and concepts of all the phenomenic areas, to both teachers and learners. . (Supplemental materials providing more detailed explanations/recommendations for classroom handling and laboratory implementation may be necessary in this respect).

For instance:
B1: space-time categorisations; invariance and symmetry enforcements; …
B2: states vs. transformations; constraints and correlations; systems-and-interactions vs. variables-and-relations; …
B3: Interaction, equilibrium (static, stationary, dynamical ones) and "differential" changes; …
B4: Interaction, conservations and "integral" changes; …
B5: Models of matter: macro vs. micro, discrete vs. continuous, …

TABLE II.C
Criteria to be enforced from the point of view of the "resonant" formalisation strategies

Several levels of *giving shape to* (formalising) physical phenomena should become gradually accessible along the curricular path: keeping in mind that many levels necessarily contribute to any meaningful understanding, and that attempting short-cuts most often directly provokes "misconceptions". It is important that different aspects are correlated to each other to promote understanding (it is not sensible to "learn to measure" without understanding the "sense of measuring"… and so on).

For instance:
C1: from observation to measurement to linear relations) One starts then by coherent natural language descriptions of the "essential" (stable in repetitions) features of the observed phenomenon: the grammatical, syntactic and semantic accuracy being eventually supported by sketchy representations. By "variations-on-the-theme" strategies one gets access to the discrimination of contextual analogies and differences, eventually expressed in the format of order relations (correlations) between sensible variables and parameters. System configurations (and their changes) can then be represented by changes in the correlations among variables, eventually represented by (or converted into) numbers and space relations. Through numbers and space the access is allowed to a coherent, "universal" representation system based on "direct" and "inverse" proportionality, eventually limited to "small enough" changes. Transduction is gradually recognized as the basic key to the phenomenological representation of physical facts.

C2: from differential modelling to conceptual structures) On this basis, the access is allowed to a crucial pivoting node of all physical understanding at pre-university level: an actual mastering of elementary (also computer-supported) techniques of "finite-differences", in handling two-variable correlations. In turn, this allows to proceed in a systematic mastering of more-than-two-variables "abstract spaces", and so on; on another side, to the crucial awareness that <the way of changing of a physical variable can be a new physical variable".

C3: from "theory" to "applications") In general, a stable variables' correlation can represent the "operational definition" of a new physical "entity" (say, exerted force and stored energy "of" a deformed spring – or field; and so on); while force-vs.-energy "formal" relationships allow to satisfactorily describe a whole set of systemic behaviours within the frame of a few regulating principles (in mechanical interactions, forces are equilibrated and energies are conserved). A very general inter-systemic modelling strategy becomes now available, in terms of "internal" state-constraints, "external" interaction constraints, and overall equilibrium conservation and invariance constraints. And as soon as such "theoretical" insights can be confidently handled (even in first-approximation formats), the route is open to a variety of technology-based applications and developments, and to new stages of systemic modelling (e.g. of microscopic, hypothetical structures).

C4: theory restructuring) An essential feature of physical-interpretation strategies is the need for periodic rearrangements of the interpretation itself, in order to match the progressive particularisation and extension of what can be accessible to experience and modelling. It is important, in our opinion, that pre-university students can directly experience (in accessible formats) the characters of such "thought revolutions". Aspects of contemporary interpretations of physical facts (taken from quantum physics, relativity physics, complexity and chaos physics, cosmological physics and so on) should therefore, in our opinion, be included in the "normal" pre-university curriculum as a cultural contribution to define the actual ways-to-look-at the world we live in.

We also gained experience from direct interventions in the dynamics of teaching innovation, involving several aspects of schooling: and this kind of experience has convinced us that in the difficult transition from validated research results to diffused, curriculum supporting teaching-principles and teaching-practices, it is realistically wise not to overlook (not to underestimate) the huge, varied obstacles and resistances that any attempt to change teaching/learning dynamics is doomed to meet. Some obstacles are exemplified in the following Table III.

TABLE III
"External" obstacles to changes in teaching

D1) At the academic level, substantially mirrored by the majority of available textbooks: where the rigidity of a traditional, unquestioned approach to "the correct Physics" is most of the times the main cause for the lack of understanding and motivation (in students as in teachers); or the hope of recovering motivation and understanding by "fancily" contextualised presentations most of the times clashes against the strategic constraints and modes of the context-independent structures of stable understanding.

D2) At the teachers' level: where the need to change one's mind when looking, thinking and acting out the Principles and Laws of Physics (forgetting about "dirty" real world), often badly interferes with the professional duty of effectively addressing and driving students' understanding on the basis of their making sense of the world they live in.

D3) At the students' level: where powerful "cultural" pressure of everyday-life habits, implicitly percolating and structuring individual thinking, often clashes with the request of explicit control of one's cognition, characterising all levels of "scientific" thinking and acting.

We think therefore that such obstacles should be taken into careful account, as "external constraints", whenever the "internal constraints" optimising a curricular project get at the stage of actual confrontation with "the world as it is". We choose not to discuss the crucial "political" aspects involved in any attempt to change the modalities of cultural transmission.

An example of phenomenological area: oscillations and waves

In order to better illustrate our proposal we have chosen Theme A5 applying the general criteria present in Tables I, II and III. (References to the tables will be of the kind (II.B1), etc). This is a transversal area of study in which concepts and models refer to physics systems (discrete and continuous mechanics, electromagnetism and optics) as well as to a wide range of phenomena (heat and temperature, acoustics, musical instruments, etc.). Transversal models allow us to emphasize the importance of analogies (formal and material) and the efficacy of the mathematical language. This area is crucial to the construction of ways of thinking, modelling, etc. necessary for the understanding basic concepts in "modern physics". As pointed out by Crawford (Waves and Oscillations, Berkeley Physics Course), "*... nowadays, although most physicists use analogies and models to help them guess new equations, they usually publish only the equations*".

In our approach we suggest teachers encourage students to look for similarities and analogies but also to point out differences between phenomena as well as the limits and pitfalls of models. The longitudinal development of the contents is based on familiarity with various examples of oscillation and waves beginning in kindergarten, both in *hands-on* and *minds-on* activities, starting with "visible" phenomena and objects using perceptual sensors. Through operational definitions and progressive semantic alterations, words such as slinky, rope, spring, diffraction grating etc. related to more familiar phenomena, thus becoming prototypes that allow the understanding of the progressive waves (mechanics, electromagnetic), eventually leading to the study of the interaction between radiation-matter, basic concepts of quantum mechanics. We strongly believe that the development of contents must be supported by experiments and simulations. We therefore suggest:

- the use of mechanical and electrical transducers at an early stage, which enables students to record and analyze properties in space and time of various types of oscillations and wave propagation (recording and analysis of sounds, etc.);
- to refer to waves and oscillation exhibits present in science centres and books which allow students to build devices with every day objects illustrating interesting phenomena (e.g. resonance);
- the use of spread sheets, specific modelling software (e.g. Interactive Physics), on line animation, etc. to introduce concepts and connect formal aspects to phenomenological ones.

In the following two tables we give out samples of a partial and "subjective" trial to organise the phenomenological area O&W in accordance with the criteria of Tables II, IIB and IIC. It must be kept in mind in our proposal teachers are required to fill out the following scheme in action research activities in schools (i.e. in local networks supported by research university groups).

Table IV
Oscillations and waves. Contents vs. competencies

Contents	Competencies
A5/1) SIMPLE OSCILLATING SYSTEMS	Identify the essential physical properties of the models for oscillating systems: (inertia, reactivity, equilibrium) and connect them with the mathematical scheme of description. Recognise the analogies between different physical systems (springs, pendulum, LC circuit, etc.). Describe oscillating systems from the energetic point of view.
A5/2) DAMPED AND FORCED OSCILLATIONS	Identify the essential physical properties: models, analogies, etc. (see above).

A5/3) COUPLED OSCILLATORS	Identify the essential features of the model, analyse the 'motion' via 'normal modes'. Apply the superposition principle (elementary Fourier analysis, beats, dispersion relations). Analyse the energy transfers. Describe the 'transition' from discrete to continuous systems (e.g.. vibrating rope). Apply to various phenomena.
A5/4)PROGRESSIVE WAVES	Describe the physical properties of waves from the kinematical and dynamical point of views. Apply the superposition principle in the analysis of wave-packets. Analyse the whole system source, medium, detector in terms of energy/impulse transfer, signal transmission, etc. Apply the principle of harmonic analysis, digital coding and reproduction. Design and realise experiments.
A5/…)	Electromagnetic waves, optical physics, polarisation, diffraction, interference, emission and absorption of the radiation, models of radiation-matter interaction, problem related to thermal equilibrium, wave-particle dilemma, from atomic structure to quantum mechanics

TABLE V
Damped and forced oscillations. Resonant cognitive-process strategies

	C1: observation, measurement, …	**C2: modelization, …**	**C3: construction of theory, …**
B1: Space, time description …	Ideal conservative oscillator: invariance and symmetry properties in space and time.	General kinematical model of a damped oscillator; phase space representation. Relationship between the physical & mathematical properties	Application to various phenomena (springs, pendulum, RLC circuits, etc.)
B3: Interaction, equilibrium …	Modes of excitation (pulses, oscillating forces, etc.).	Ideal and real oscillators and the equilibrium state	
B4: conservation principles …		Real dissipative oscillator, dumping factor, mathematical modelling, phase space representation	
B5: Models of matter …			Criteria of 'translation' from the local to the global description (use of Fourier Transform)

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A NEW RESEARCH-BASED CURRICULUM FOR TEACHING MEASUREMENT IN THE FIRST YEAR PHYSICS LABORATORY

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A new introductory physics laboratory course based on the probabilistic interpretation of measurement and measurement uncertainty (as recommended by the International Organization for Standardization) has been designed and evaluated. The approach is described, as well as the results of an evaluation of the new course piloted at the University of Cape Town. Student responses to written probes administered at the beginning of the year are compared to those written after the laboratory course. The "point" and "set" paradigms are used as a model to analyse the responses to the probes.

Introduction

The goals of first year physics laboratory courses are often ambiguous. Although in many cases the purported aim is to illustrate some aspect of theory, a perusal of first year laboratory manuals shows that teaching the fundamentals of measurement and data analysis is nearly always a primary goal as well. The assumption which is often made is that students will develop their understanding of the nature of measurement and experimentation by simply carrying out data analysis prescriptions. Recent research studies have, however, questioned this assumption (Buffler, Allie, Lubben & Campbell, 2001; Evangelinos, Psillos & Valassiades, 2002). They have pointed to the fact that students who have completed an introductory physics laboratory course are often able to apply techniques in a mechanistic way (e.g. calculating means and standard deviations, fitting straight lines, etc.), but lack an appreciation of the nature of scientific evidence, in particular the central role of measurement uncertainty. As an example, Lippmann (2003) finds that before instruction only one in eight students use the notion of range for comparing sets of results, and even after a reflective laboratory course, less than half of them do so.

Problem with the "traditional" laboratory course: lack of coherence

Instruction in data analysis in introductory physics laboratories is usually given as a combination of apparently rigorous mathematical computations and vague rules of thumb which students are seldom able to synthesise into a coherent whole. A large part of the problem lies with the logical inconsistencies that are inherent in traditional ("frequentist") data analysis which is based on the analysis of frequency distributions.

For example, one particular difficulty of this approach is how to deal with a single measurement when the frequentist theory requires large numbers of readings to be processed. Even when students do take several readings, it is typically of the order of 5 or 10 rather than the 20 or 30 that is suggested by frequentist theory. Consequently, the logical inconsistencies in the traditional approach to data treatment appears to further cultivate students' misconceptions about measurement in the scientific context.

Problem with the "traditional" laboratory course: students' prior views

A second weakness of many introductory physics laboratory courses is the lack of cognisance of students' prior views about measurement. Over the past few years we have researched first year physics students' understanding of the nature of measurement (Buffler *et al.*, 2001; Lubben, Campbell, Buffler, & Allie, 2001). A model of student thinking about measurement has been developed which has been termed "point" and "set" paradigms. The **point paradigm** (see Table 1) is characterized by the notion that each measurement yields either the correct (true) value or an incorrect value of the quantity being measured (the measurand).

As a consequence each measurement is regarded as independent of the others, except to confirm or reject a specific value, and individual readings are not combined in any way. This way of thinking thus also manifests itself in the belief that only a single (very careful) measurement is required in principle to establish the true value. If an *ensemble* of readings with dispersion does emerge, representations of the measurand are based on the individual data points only, such as for example, the selection of a recurring value in the data set or a one-to-one comparison of data values between different data-sets.

On the other hand, the **set paradigm** (Table 1) is characterised by the notion that each reading is an approximation of the measurand and that knowledge about the measurand can never be perfect in principle. The most information regarding the measurand is obtained by using all available data to construct distributions from which the best approximation of the measurand and an interval of uncertainty are derived. In nearly all practical situations in the introductory laboratory, the best approximation of the measurand will either be the reading itself (in the case of a single reading) or the calculated average value of a set of repeated readings.

In summary, the key difference between the two paradigms is that students using the point paradigm draw conclusions about the measurand directly from individual data points, while those using the set paradigm draw conclusions about the measurand from the properties of the distribution constructed from the whole ensemble of available data. The point paradigm can be regarded as a local realistic way of viewing data while the set paradigm uses theory to relate the data and the measurand.

Table 1. The point and set paradigms.

Point Paradigm	**Set Paradigm**
The measurement process allows you to determine the true value of the measurand.	The measurement process provides incomplete information about the measurand.
"Errors" associated with the measurement process may be reduced to zero.	All measurements are subject to uncertainties that cannot be reduced to zero.
A single reading has the potential of being the true value.	All available data are used to construct distributions from which the best approximation of the measurand and an interval of uncertainty are derived.

An important feature of the set paradigm is the construction of *distributions* from the data. At this point a debate arises as to whether to use frequency distributions or whether in fact the distributions are probability distributions. In contrast with the traditional "frequentist" approach, the International Organization for Standardization (ISO) has recommended that the "probabilistic" perspective become the standard way for dealing with experimental measurements in all scientific work. The reasons for doing so and the details of the recommendations are discussed below. At the outset, though it should be noted that one of the attractive features is that the theory based on probability distributions is applied in the same way to a single reading as to an ensemble (Allie, Buffler, Campbell, Evangelinos, Lubben, Psillos & Valassiades, 2003).

A probabilistic interpretation of measurement

The need for a consistent international language for evaluating and communicating measurement results prompted (in 1993) the ISO (International Organization for Standardization) to publish recommendations for reporting measurements and uncertainties based on the *probabilistic interpretation of measurement.* All international standards bodies, including the IUPAP (International Union of Pure and Applied Physics) and IUPAC (International Union of Pure and Applied Chemistry), have adopted these recommendations for reporting scientific measurements.

A number of documents currently serve as international reference standards. The most widely known are the *International Vocabulary of Basic and General Terms in Metrology* (ISO, 1993) and the *Guide to the Expression of Uncertainty in Measurement* (ISO, 1995). A shorter version of the latter is publicly available as NIST Technical Note 1297 (Taylor & Kuyatt, 1994).

The recommended approach (ISO 1993, 1995) to metrology is based on the use of probability theory and the concept of the probability density function for the analysis and interpretation of data. A key element of the ISO guidelines is how it views the measurement process. The guidelines state that "In general, the result of a measurement is only an approximation or estimate of the value of the specific quantity subject to measurement, that is, the measurand, and thus the result is complete only when accompanied by a quantitative statement of its uncertainty." Uncertainty itself is defined as "a parameter associated with a measurement result, which characterizes the dispersion of the values that could reasonably be attributed to the measurand" (ISO 1993, 1995).

At the beginning of the measurement process, new data are combined with all prior information about the measurand to form an updated state of knowledge from which inferences about the measurand are made. The formal mathematics used to allow these inferences are probability density functions (pdfs) with the (true) value of the measurand as the independent variable. (We note that there is no difference between the terms "the value of the measurand" and "the true value of the measurand"). Thus, the measurement process includes using a pdf which best represents our knowledge about the measurand.

We emphasize that both the case of the single reading and the case of a set of repeated readings with dispersion, involve seeking the pdf for the measurand. The last step in the measurement process involves making inferences about the measurand based on the (final) pdf.

Although the ISO recommendations do not refer explicitly to the underlying philosophy, the formalism relies on the Bayesian approach to data analysis. The final pdf is usually characterized in terms of its location, an interval along which the (true) value of the measurand may lie, and the probability that the value of the measurand lies on that interval. In metrological terms these are, respectively, the **best estimate** (or **best approximation**) of the measurand and its **uncertainty**, and the **coverage probability** (or **level of confidence)**, calculated as the percentage area under the pdf defined by the uncertainty interval.

Typical statements describing a measurement result are of the form "the best estimate of the value of the measurand is X with a standard uncertainty U and the probability that the measurand lies on the interval $X \pm U$ is Z %". In this approach, instrument readings are considered as constants, while the concept of probability is applied to any claims made about the *value of the measurand* which is considered *the random variable*.

The new laboratory course

The materials for the new laboratory course attempt to weave together the students' prior knowledge about measurement, our desired learning outcomes for the laboratory and the nature and philosophy of experimentation as specified by the ISO recommendations (ISO 1993, 1995).

An interactive student workbook has been written which aims to introduce the main ideas of measurement and uncertainty. Students work through the activities in the workbook in small groups in a tutorial-type environment and are assisted when necessary by one of a number of roving tutors. On alternate weeks, the students are engaged in activities in the laboratory which are designed to support the new ideas about measurements and provide "hands-on" laboratory experiences. At the same time, reporting on a completed experiment forms a central part of the experience and producing writing-intensive reports provide additional learning and assessment opportunities (Allie, Buffler, Kaunda & Inglis, 1997).

In general the laboratory tasks are framed in the form of authentic problems that require an experimental investigation for their resolution and have to be reported on to a particular audience. The course consists of a 3-hour session per week for 16 weeks and was piloted with a first year class of students in the Physics Department at the University of Cape Town in 2002.

Evaluation of the new course

The evaluation of the new course involved the diagnostic testing of the students both before and after the course as well as a number of interviews with individual students. The written research instrument comprised a set of fourteen written probes (questionnaire items) adapted from those developed for a previous study (Buffler *et al.*, 2001). All probes were answered individually in strict sequence under examination conditions. Each probe presented a situation where a procedural decision was necessary and offered a number of alternative actions from which a choice was required. The reason for choosing a particular action was then requested in written form. Procedural decisions are difficult to explore through written probes since respondents often have difficulty in visualizing 'thought experiments'. In order to minimize this problem, all the probes were related to the same experimental context (Buffler *et al.*, 2001) A large-scale version of the apparatus was also used to demonstrate the 'experiment' before the probes were answered.

The probes were completed by 106 first year physics students. The particular cohort of students used in this study may be generally characterised as having had science teaching at school which was insufficient in depth for university study, learn in English as a second language and come from socio-economically disadvantaged backgrounds (Allie & Buffler, 1998). The instrument was administered during registration week, before the start of coursework, and then again after completion of the new laboratory course. The analysis of the probes included categorising the student responses according to the answer choice (A, B or C) together with the different types of reasoning evidenced in the justification for this choice. The coding of the responses was undertaken using an alphanumeric scheme which had been developed and tested previously (Buffler *et al.,* 2001). This coding scheme enabled the identification of whether the point or set paradigm informed a student's decision in each probe.

Results

The responses from all probes were combined to form a single classification for each student (pre- and post-testing). The results are shown in Table 2. A "mixed paradigm" classification was used when there was not a clear indication of whether the student was using the point paradigm or set paradigm across the entire set of probes. It can be seen from Table 2 that before the course 73% of the sample were classified as using "consistently point paradigm" and 26 % as using "mixed paradigms". After the course the vast majority of the sample (89%) were classified as "consistent set paradigm" with 9% using "mixed paradigms".

These outcomes may be compared with the results from a similar set of probes administered two years prior to a cohort of 70 similar students attending the "traditional" version of the same course (Buffler *et al.*, 2001). For this cohort very similar pre-course perceptions (67% using "consistent point paradigm" and 25% "mixed paradigms" were found. However, a much smaller percentage of the students in the traditional course were classified as "consistent set paradigm" after their course (16% compared with 89% after the new course).

Table 2. Students' use of paradigms based on all probes before and after instruction.

		Paradigms used **after instruction**			
		Consistent point paradigm	Mixed paradigms	Consistent set paradigm	**Total**
Paradigms used **before**	Consistent point paradigm	0 (0%)	7 (7%)	70 (66%)	**77 (73%)**
	Mixed paradigms	1 (1%)	3 (3%)	24 (22%)	**28 (26%)**

instruction	Consistent set paradigm	0 (0%)	0 (0%)	1 (1%)	**1 (1%)**
	Total	**1 (1%)**	**10 (9%)**	**95 (89%)**	**106 (100%)**

Conclusion

The materials in our new course try to take into account students' prior knowledge about the nature of measurement and we have adopted what we believe to be a logically consistent framework, i.e. the probabilistic approach to measurement and uncertainty as advocated by the ISO. This approach leads directly to inferences about the measurand in a natural way, in both cases of single and repeated observations. Our evaluation of the pilot version of our new course has indicated that it is much more successful than the traditional course in moving students' understanding towards the "set paradigm" of measurement. Since other research findings (for instance Campbell, Allie, Buffler, Kaunda, & Lubben, 2000) indicate that responses to hypothetical scenarios of experimental work do not always correspond with decisions that students make in practice in the laboratory, further observational studies are needed to confirm these apparently positive findings.

When the data from the probes are considered together, there is compelling evidence that most students come to university with a view that the objective of scientific measurement is "exactness", one of the main indicators of the operation of the point paradigm. This view is related to two underlying ideas of the nature of experimentation in physics. Firstly, high quality measurement is equated with 'accuracy', and in many cases students use the terms 'good results' and 'accurate results' interchangeably. Secondly, it seems that many students perceive the purpose of collecting experimental data is to identify numerical values for substitution into formulae.

Since mathematics deals with either specific symbols or numbers, it is clear that the notion of an interval as a result from a physics experiment falls outside of this framework. Although many students use the word "approximate" when considering a single reading in a scientific context, the data indicate that this is not meant to indicate a "fuzzy" (extended) point, but rather a point "close to" a particular reference, which is either the perceived true value or the nearest mark on the measuring instrument. A number of further issues do arise from our data. In particular, many students appear to reason using intervals without an apparent understanding of the nature of a measurement result. Although most students were able to apply interval reasoning appropriately to situations where, for example, they were asked to compare two measurement results for agreement, from written responses to other questions it became clear that many students had an inappropriate understanding of an interval, especially with regard to it representing a pdf. An updated version of the new materials is being used and evaluated in the Physics Department at UCT in 2004.

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A MORE COHERENT TOPIC SEQUENCE FOR E&M

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The traditional sequence of topics in the E&M portion of the calculus-based introductory physics poses serious conceptual problems for the student. New concepts are introduced extremely rapidly; abstractions are layered on top of abstractions; complex mathematical formalisms are introduced rapidly; and the student is expected to assimilate all of this quickly. To many students it is not even clear what phenomena this elaborate formalism is designed to explain. Further, topics are presented in an intrinsically fragmented way. The concepts of charge, electric field, and flux, introduced in electrostatics, are abandoned entirely in the treatment of circuits, which deals with current and potential. Magnetic field is introduced very late. At the end of the traditional course, it is not uncommon for students still to be confused about the difference between charge and field.

We have addressed these issues by making two fundamental changes in the curriculum. First, we have emphasized an intermediate level of abstraction, focusing on field as a primary concept at an intermediate level of abstraction, and a coherent thread throughout the course, including circuits. Second, we have altered the sequence of topics, introducing magnetic fields early, to strengthen students' comprehension of the field concept; and we have delayed topologically and mathematically complex topics such as Gauss's law until late in the course, when students have accumulated extensive experience with 3D patterns of field in space and with the charge distributions responsible for these fields. In the traditional sequence magnetic field and magnetic force are introduced quite late in the course, when students (and instructors) are tired and have little remaining time to gain adequate experience with the topic, or to compare and contrast electricity and magnetism. Early introduction of magnetic field bolsters student understanding of the field concept, because the analysis of magnetic interactions necessarily requires the two-step process of thinking about fields and then forces. Faraday's law is more difficult when student experience with magnetic field has been quite brief, and when the flux concept has already been forgotten, whereas in our curriculum the juxtaposition of Gauss's law and Faraday's law reinforces the concept of flux, and students have worked with magnetic fields and forces for many weeks before encountering Faraday's law. See http://www4.ncsu.edu/~rwchabay/mi.

Why E&M is difficult for students

Traditionally students are introduced to electricity and magnetism (E&M) in the second half of the introductory calculus-based physics course, after they have completed an introduction to classical mechanics. Even students who have done well in the first part of the course often see E&M as difficult and confusing.

In E&M, students suddenly encounter for the first time a level of abstraction and mathematical sophistication far beyond what they experienced in mechanics. In mechanics, many situations involved familiar macroscopic objects: balls and sticks, cars and airplanes. At least some important concepts, such as velocity and force, were easily related to everyday experience.

In E&M the student is suddenly introduced to a world in which almost all of the things under consideration are invisible; they are either microscopic, like electrons, or abstractions, such as field, flux, and potential. Integral calculus becomes a central mathematical tool, and students are asked to apply it in unfamiliar ways, such as calculating the path integral or surface integral of a quantity expressed as a vector dot product.

In the traditional introductory E&M sequence, this conceptual and mathematical complexity is exacerbated by the extraordinarily rapid introduction of a long sequence of new concepts. The ideas of charge, electric force, field, flux, and Gauss's law are often presented within the first week of the course. These are quickly followed by the concepts of potential, potential difference, and electric current. Students may be overwhelmed by this rapid piling up of abstract ideas, and usually are not given sufficient practice to be able to apply these concepts reliably, nor to discriminate them from each other. Indeed, it is not uncommon to hear instructors complain, at the end of a semester, that a significant fraction of their students still do not know the difference between charge and field. By the end of the course, it is not unusual for good students to have forgotten the expression for the electric field of a single point charge, since this has not been used for many weeks.

Goals of the introductory E&M sequence

Some research and development in physics education has focused on remedying particular problems with this sequence, by giving students additional focused practice on one concept or another. We have chosen instead to re-examine the intellectual structure of the E&M curriculum, in an attempt to identify which concepts are centrally important, how these concepts are related, and how they may be introduced to students in a coherent, comprehensible sequence. Our overall goals are those of the *Matter & Interactions* curriculum (Chabay & Sherwood, 2002), which is discussed elsewhere in this volume. The goal of the *Matter & Interactions* (M&I) curriculum is to engage students in the contemporary physics enterprise, by emphasizing:

- A small number of fundamental principles, from which students start analyses
- The atomic nature of matter, and macro/micro connections
- Unification of topics, facilitated by the atomic view of matter
- Modelling physical systems, including computational modelling

Field: An intermediate level of abstraction

The concept of field is central to electricity and magnetism. However, in the traditional introductory course, this concept is not used at all during large sections of the course, including those sections dealing with electric circuits and with Faraday's law.

Consequently, the field concept does not appear central to students, who are kept busy plugging numbers into formulas for equivalent resistance and mutual inductance. Our goal, in the redesign of the E&M sequence, was to make the field concept appear both important and useful to the students in the course.

The field concept is a significantly more abstract concept than any of the quantities typically used in mechanics. The effort required to understand and become comfortable in using this concept is, however, justified by the immense gain in predictive and explanatory power it affords. In particular, the classical model of electromagnetic radiation is truly incomprehensible to a student who has not mastered the concepts of electric and magnetic fields.

Like the Newtonian synthesis in mechanics, Maxwell's equations and his explanation of the nature of light are one of the crowning intellectual achievements of classical physics. Introductory students are capable of understanding this triumph if and only if they have had sufficient practice and sufficiently varied experiences with the concepts of electric and magnetic fields, and their effects on matter, before they reach this complex idea. For this reason, and because the field concept alone affords students the opportunity to gain significantly in intellectual sophistication, we have made the field concept the central focus of the introductory E&M sequence, and the backbone of the story told in the course.

In the remainder of this paper we discuss details of an altered sequence of topics designed to focus on the field concept, including the late introduction of Gauss's law and the early introduction of magnetic field.

Gauss's law

In the traditional sequence Gauss's law is introduced very early, sometimes during the first week of the course. Generations of physics teachers have lamented the fact that the students just don't understand Gauss's law. But from a cognitive point of view it is quite clear why this happens despite the best efforts of good teachers. At this early stage of the course, students are struggling with what is for many of them a subtle distinction between charge and field, yet Gauss's law embodies a complex topological relationship between charge and patterns of field in three-dimensional space. Early in the course students have had no experience with the kinds of patterns of field that are possible in space, but these patterns of field lie at the heart of the topological relationship. Surface integrals are typically unfamiliar to students, so flux is a challenging concept. Moreover, students have had little experience visualizing 3D geometries, nor have they had prior experience with symmetry arguments of the kind that play a large role in the actual applications made of Gauss's law. All these multiple conceptual problems and barriers make introducing Gauss's law early in the course a pedagogical disaster.

Why is Gauss's law introduced early? The real justification is that it is needed to prove three important properties of electrostatics, that charge is found only on the surface of a conductor (not in the interior), that the electric field inside a conductor (and inside an empty cavity in a conductor) in static equilibrium is zero everywhere, and that the field of a uniformly charged spherical shell is zero inside and point-like outside. However, early in the course students are not able to understand the elegant proofs constructed with Gauss's law! Probably the reason Gauss's law has traditionally been treated early is to satisfy the desire for rigor on the part of the teacher. Unfortunately, at this point it is only the instructor who is able to appreciate this rigor.

Because it poses such conceptual challenges for students, we have delayed the introduction of Gauss's law until much later in the course. How do we introduce the properties enumerated above? We make all three results plausible, and state that we will later prove them rigorously, when we discuss Gauss's law. Students are quite willing to accept this approach.

Because we have emphasized the microscopic structure of conducting materials, we are able to prove by contradiction that if there were a nonzero electric field the mobile charges would move, which contradicts the assumption of static equilibrium. (This argument is not sufficient to prove that the electric field in an empty cavity within a conductor in static equilibrium is zero.)

The electric field of a uniformly charged spherical shell can be derived by brute force using calculus. We show how to set up the integral over the charge distribution but explain that an easier route to the final result will be available later using Gauss's law. Gauss's law is often used to obtain the electric field of an infinite uniformly charged plate and an infinite uniformly charged rod, but we obtain these results from limiting cases of the finite disk and finite rod, which are derived fairly easily by integration. There is a pedagogical advantage to emphasizing large but finite charge distributions rather than infinite ones, since the latter can raise awkward conceptual issues. (For example, a student correctly pointed out that it would take infinite time to charge a capacitor with infinite plates.)

In M&I, Gauss's law is introduced about two thirds of the way through the course, at the point where students have had a great deal of experience with patterns of electric (and magnetic) field in three-dimensional space. We exploit this familiarity to introduce Gauss's law first in a qualitative, visual form that emphasizes what students already know about patterns of field in space and the distributions of charge responsible for them. Qualitatively, using dynamic 3D computer visualization software (supported by static figures in the textbook), we show that there is a relationship between the amount of charge inside a closed 3D surface and the surface integral of field on that surface. Only after making the topological connection plausible do we prove the formal quantitative version of Gauss's law. We then use Gauss's law to prove that there cannot be any nonzero charge density in the interior of a conductor, and that the electric field inside a conductor in static equilibrium (and inside an empty cavity) must be zero. We also do the usual applications of Gauss's law to the field of a sphere, rod, and plate.

Our experience is that students are able to appreciate the nature of Gauss's law when presented late in the course, and can use Gauss's law to relate charge and field. Ampere's law, which, like Gauss's law, involves patterns of field in space, is treated in the same chapter, after a discussion of Gauss's law for magnetism and the apparent absence of magnetic monopoles.

Magnetic field

In the traditional sequence magnetic field and magnetic force are introduced quite late in the course, after electrostatics and circuits. There are many disadvantages to this delay. A purely pragmatic issue is that late in the course students are tired, and unenthusiastic about confronting a challenging new concept. If magnetism is introduced very late, students have little remaining time in the course to gain adequate experience with the topic, and little time to compare and contrast electricity and magnetism. Faraday's law is made more difficult when students' experience with magnetic field has been quite brief.

Perhaps more seriously, experience with magnetic field and magnetic force is necessary to solidify students' understanding of the concept of field. Even strong students are frequently disconcerted when, late in the course, they find themselves struggling with the concept of field in this new context. We surmise that in the analysis of electric interactions it is possible for students to imagine distributions of source charges interacting directly with other charges, instead of focusing on field as a mediator of the interaction. However, the complex spatial nature of magnetic interactions leaves no alternative to the two-step process of determining the magnetic field due to the source charges, then using this field to find the direction and magnitude of magnetic forces.

Besides strengthening students' understanding of fields, the early introduction of magnetic field allows students to use the magnetic field of moving charges as a probe of current in electric circuits. Initially, we view magnetic field operationally as a field that affects a compass. It is produced by moving charges, and students observe the magnetic effects that currents in simple circuits have on a nearby compass. They observe the magnetic field near a coil and a bar magnet and identify a dipole-like pattern familiar from earlier work with electric dipoles. An atomic model allows students to predict the magnetic dipole moment of a bar magnet, and confirm their prediction by using a compass to measure it.

In the traditional sequence electric field is dropped once circuits are introduced, and magnetic field is not introduced until after the study of circuits is completed. In contrast, in M&I both electric and magnetic field remain central throughout the subsequent chapters on circuits. The treatment of circuits, discussed below, focuses on microscopic description and analysis. The deep sense of microscopic mechanism enriches the understanding of Kirchhoff's loop and node rules, and provides additional practice with electric and magnetic fields and their relationship to each other. The chapter on magnetic force also makes strong connections to electric field and force, and to modern physics.

In particular, a simple example of two protons repelling each other, viewed from two different reference frames, shows how electric and magnetic effects are dependent on the choice of reference frame, and offers the opportunity to explore the idea that time runs differently in different reference frames.

As a result of this altered sequence, students have many weeks of experience with magnetic field, and many weeks of experience in comparing and contrasting electric field and magnetic field, including engaging in frequent tasks involving both kinds of field.

Faraday's law

Faraday's law is usually difficult for students. It involves a dynamic connection between magnetic and electric phenomena, introduced at a time when students have had only a rather brief exposure to magnetic field. Moreover, the integral form uses the concept of flux, which is typically introduced at the start of the course in the context of Gauss's law but not used again until much later, with the introduction of Faraday's law. The effect is to use a forgotten concept (flux) to relate a line integral of electric field (emf) to the time derivative of the surface integral involving a quantity with which the students have had inadequate practice (magnetic field). It is not surprising that Faraday's law is usually difficult for students.

With the new E&M sequence Faraday's law is surprisingly easy. It is introduced with emphasis on the curly electric field that is found surrounding a region of time-varying magnetic field. Students at this point in the course have had lengthy experience with both electric field and magnetic field, including their patterns in space. The flux concept is fresh in their minds, because Gauss's law is treated immediately preceding Faraday's law. The combination of long-term experience with magnetic field and the just-in-time teaching of the flux concept makes Faraday's law quite accessible to students.

While we have found it completely feasible to introduce magnetism early and use it repeatedly, it would be difficult to find appropriate applications of the flux concept to sustain and build student facility with the concept, even if it were possible to teach Gauss's law at the start of the course. Hence there is another advantage to introducing the flux concept just in time, immediately preceding Faraday's law. It is worth noting that we discuss motional emf in the chapter on magnetic force, well *before* introducing Faraday's law. This helps make an important distinction between these two very different mechanisms for producing emf, whereas in the traditional sequence the two effects are often not clearly delineated.

Electromagnetic radiation

After dealing with Gauss's law for electricity and magnetism, Ampere's law, and Faraday's law, we are ready to consider Maxwell's extension to Ampere's law and show that crossed electric and magnetic fields can propagate in empty space, at the speed of light. With diagrams showing the effects of retardation we make it plausible that an accelerated charge would produce radiation, and we state without proof the formula for the fields of an accelerated charge, so we have a mechanism for the production of radiation. This sense of mechanism makes accessible the classical interaction of electromagnetic fields with matter.

The course all along has emphasized the effect of fields on the charged particles of which matter is composed, so it is easy and natural to talk about the acceleration of electrons in matter by the electric field in incident radiation, and subsequent re-radiation by these accelerated electrons. This view brings to physical optics a clear sense of mechanism. Moreover, because the preceding mechanics course includes discussion of photon emission and absorption, we are now in a good position to discuss wave-particle duality.

Unifying electrostatics and circuits

One important aspect of the M&I curriculum involves the unification of topics traditionally presented as unrelated. In the traditional introductory E&M course electrostatics and circuit phenomena are treated as nearly completely separate subjects. Electrostatics is discussed in terms of charge and field, but circuits are discussed exclusively in terms of current and potential, and the concept of electric field is dropped from view, never to return.

Inspired by Haertel (1987), we first engage students in the analysis of circuits from a microscopic point of view. Ohmic materials are described in terms of the microscopic relation $v = uE$, where v is the drift speed, u is the mobility of the mobile charges, and E is the electric field. The field inside circuit wires is shown to be due not only to charges in and on the battery but also to those on the surfaces of the circuit elements. Students learn to analyze both DC and RC circuits directly in terms of the Coulomb interaction and the atomic nature of matter. This analysis in terms of charge and field makes a strong connection with electrostatics, unifying the two topics, and it provides a strong sense of mechanism for the behaviour of simple circuits.

Overview of the new sequence

- Stationary charges (4 weeks)
  - Electric field; effect on matter; field of distributed charges; potential
- Moving charges (5 weeks)
  - Magnetic field; microscopic view of circuits; macroscopic view
  - Magnetic force, including motional emf
- Reasoning about patterns of field in space (1 week)
  - Flux and Gauss's law; Ampere's law
- Time-varying fields, accelerated charges (4 weeks)
  - Faraday's law: curly electric field associated with time-varying magnetic field; induced emf
  - Ampere-Maxwell law; electromagnetic radiation; radiation by accelerated charges
  - Physical optics; wave-particle duality

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COMPUTATIONAL PHYSICS AT THE UNIVERSITY OF KWAZULU-NATAL, PIETERMARITZBURG

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The University of KwaZulu-Natal, Pietermaritzburg is the first South African university to teach a fully-fledged undergraduate programme in computational physics. This paper gives a brief outline of the programme structure and the programme modules. Potential pitfalls are pointed out and best practice suggested for the successful implementation of such a programme. Careful attention is placed to the assessment methodologies.

Introduction

When I arrived at the University of KwaZulu-Natal (UKZN) in 1997, I realized very quickly that I was not going to be able to attract the type of research student that I desired into my field of research, namely computational solid state physics. In fact, the numbers of students pursuing physics at the highest level in our department had already been dropping steadily over the years.

Our students were simply not sufficiently computationally competent. They did not have a culture of writing computer code to solve physical problems of interest – whenever a computational solution was sought, the first port-of-call, even amongst many fellow academics, was the internet, to try to find a package that was readily available, often at an exorbitant price. The prevailing attitude was to fit the computer package to solve the problem.

I believe that we in Africa have the potential to excel in the computational sciences, and that every effort should be made to realize this potential. Computers are reasonably cheap, and by using freeware operating systems and compilers as well as graphical packages, we can entrench a culture of hands-on computing. In so doing, we can leap-frog evolutionary developments and begin to work at the very cutting edge of science and technology. India has been very successful in this domain, and today many Indian computer software engineers working both on the sub-continent as well as in the USA are making significant contributions to computer code development in the commercial world.

At the UKZN, our undergraduate programme in computational physics has gone a long way toward addressing a real need in our education. In so doing, we have breathed new life into the study of physics. We have over recent years had some of the highest numbers of honours students in physics in the country. Many of our students have been able to secure substantial scholarships from private industry for study at our institution. We maintain strong linkages with industry, and many of our graduates have been successfully placed in industrial jobs.

Second year

I will not attempt to embark on a detailed presentation of the programme modules because of obvious space limitations. Much of the ensuing discussion is based on the programme structure as it is presented in the Appendix. I will make general comments about some of the salient points regarding both the programme structure and modules.

It is probably not possible to introduce computational physics at the first year level because of the large number of students involved. It is necessary that one has an undergraduate LAN comprising of about 30 personal computers, and these resources will be severely taxed at the first year level.

It is my view that one should make maximal use of freeware software, and so in this regard the Linux operating system is recommended. Unfortunately, at Pietermaritzburg, we have been constrained into using a windows-based system only because our LAN is being shared by students from other disciplines. A dual-bootable system is an alternate solution, but in our case this would have required a more involved systems administrator which we could not afford. We intend to move over to an exclusively Linux-based LAN in the very near future.

Second year, first semester

It is important that one focuses on the basic techniques of computational physics early on. We made a concerted decision to use FORTRAN 90/95 as our programming language of choice, and so we teach this material formally in an 8 credit module comprising 24x45 minute lectures plus 10x3 hour laboratories. Obviously, there are other programming languages that one could choose from, such as java, c, c++, etc. However, it must be pointed out that, insofar as numerically intensive computing is concerned, f90 is very competitive with the other languages. Many of the numerical libraries written in FORTRAN, that have been developed over the years, are highly optimised for the types of applications that one encounters in physics. Furthermore, at a university such as ours, and I suspect at many other South African universities, it is very difficult to teach material which might otherwise be considered to being in the domain of another discipline – in this case, computer science, so FORTRAN remains a sensible choice. It is not advisable to proliferate with programming languages at this level.

Fortran is one of the oldest programming languages, and for a long time suffered from this stigma. However, the 90/95 version of the compiler has certainly brought in many modern features such as allocatable arrays and derived data types that have widened the scope of the language. At any rate, students – especially young students – must be able to pick up the skills of another language after learning the rudiments of programming in another context. The modern computing age demands that one develops an ability to adapt to a changing environment.

The FORTRAN that we teach is almost always in the context of physical applications, see for example the first six chapters of Hahn [Hahn 1994]. We introduce simple numerical techniques such as numerical differentiation and integration. Our students begin plotting results in 2 dimensions using gnuplot.

It is our experience that our students entering into second year are not sufficiently competent in basic calculus, and so rather than relying on our mathematics department to teach the material, we have developed our own 8 credit module on mathematical methods for physicists. Mathematics is too basic a subject to have our students only exposed to the formal esoteric aspects of the material that is usually presented by our mathematics department. Especially because many of our students come from impoverished mathematical backgrounds stemming from poor high school teaching, it is crucial that we get our students up to speed on the practical applications of mathematics.

We do not teach our mathematical methods module in lieu of second year mathematics, but in addition to it. This way, our students can plod through the formal aspects and appreciate the basis theorems whilst they are, at the same time, schooled in practical applications. One example that ably demonstrates the connections between mathematics, computer coding and graphical work centres on the following problem: write a simple FORTRAN code to compute the 1st order, 3rd order, 5th order, etc. Taylor expressions for sin(x); plot all curves on the same graph and notice the convergence of the high order expressions to the exact functional form in the vicinity of the origin. The graphical presentation of the results is very illuminating.

Second year, second semester

In the spirit of teaching basic techniques in computational physics in second year, we have designed an 8 credit module on Mathematica [Wolfram (1999)]. The material is directly out of part I of Wolfram's book, although we focus a lot on physical applications based on second year physics.

The second 8 credit module is on computational classical mechanics. This is the first opportunity to apply some of the computational techniques studied earlier almost wholly to physical applications. There is no limit to the types of problems that one may consider – in fact, many of the text books on computational physics for undergraduate students focuses quite intensely on classical mechanics applications. Many of the problems are based on the initial value problem, for example solving for the motion of a rocket taking into account a variable mass and air friction. We also study the chaotic pendulum. Basically, with a little imagination, one can turn many conventional classical mechanics problems into an analytically intractable one for which a numerical solution on the computer is sought. The students also begin to gain competence in both 2-dimensional and 3-dimensional graphical work. This module presents an opportunity to discuss more advanced numerical methods [Devries (1994), Giordano (1997), MacKeown (1987), Pang (1997), Press (1992), Vesely (1994)].

Third year

There is a close mirroring of modules taught in the mainstream physics programme and those taught in the computational physics programme (see Appendix). The general scheme adopted at third year level is one for which the theoretical material is covered in the mainstream programme so that one can work almost entirely on algorithmic issues and computer code development in the computational programme. We focus almost exclusively on physical applications. Because of human resource limitations, we only offer half a major of computational physics. Our students are required to pick up the other half major from mathematics, computer science or statistics (all at the third year level). If teaching resources permit, it is recommended that computational physics be taught as a full major.

Third year, first semester

The computational quantum mechanics module centres on the numerical solution to the boundary value problem. Students write computer code to solve for the energy eigenstates of the hydrogen atom, the square-well potential and the harmonic oscillator. The analytical solutions to these problems provide a tangible means of testing the accuracy of their numerical methods. Thereafter, students solve for a wide range of one-dimensional problems – in each instant, there is only a change in one or two lines of code (or, in some instances, a single subroutine or function) that defines the potential.

Qualitative understanding is derived after a series of numerical experiments that involve changing the potential. For example, students are asked to notice that in regions where the potential well is deep, the wave function is more ‘wiggly’: More curvature means more kinetic energy which you expect in regions where the potential energy is low because of energy conservation. Students numerically calculate expectation values, and first-order and second-order perturbative corrections to the energy spectrum, etc. Once again, there is no limit to the type of numerical problem that one can tackle.

The computational statistical physics module involves enumerating the states for a variety of systems including the harmonic oscillator, ideal gas and the spin 1 paramagnetic fluid. Efficient schemes are devised to compute the entropy within the microcanonical ensemble from which a range of physical properties of the system may be derived, such as the temperature, heat capacity, etc. The same physical systems are then studied within the canonical ensemble where the partition function plays the central role – and so there is a concerted effort at computing this object efficiently. There are several other problems that the students tackle including studies of thermodynamic cycles and the simulation of ideal and real gases using a simple molecular dynamics scheme.

Third year, second semester

Once again, I only comment briefly on the modules on offer. The first 8 credit module on advanced statistical physics is really a module on *random* systems which is intimately connected with the Monte Carlo method. As an introduction to this module, students study random numbers by testing the quality of random numbers generated by the intrinsic call function and by writing their own random number generator. Various cellular automata models are then considered, such as random walks, diffusion, percolation, sand pile models, the Ising model, etc. The Monte Carlo method as an efficient means of computing high-order integrals is also studied.

The second 8 credit module on computational solid state physics follows closely on the heels of the theory module. Example projects and exercises are based on studies of crystal structures, x-ray diffraction, lattice vibrations, energetics of solids (based on a simple pair potential), etc., the details of which are beyond the scope of this brief paper.

Assessment

In real world situations, it does not usually happen that one has to produce a substantial piece of working code over a period of only a couple of hours, so it would be extremely unfair to have students develop code under examination conditions. Project work and computational exercises coupled with continuous assessment is more appropriate for computational physics.

The instructor has to ensure that students submit their *own* work. This is a bane for the instructor since computer code can be so very easily plagiarised. A special effort must be made to ensure that the grade reflects the student's own effort as well as their ability. This can be achieved in a variety of ways:

1. Project submission: The basic algorithm structure could be discussed in class, which I call the *standard solution*. Students given an extra grade for 'extra effort' which could involve:
    a. Using more advanced features of the programming language; structuring the code in modular fashion using function calls and subroutines
    b. Producing computationally more efficient code in terms of compute time and/or memory usage
    c. Documenting the code carefully
    d. Applying the code to novel physical situations not discussed in class
    e. Researching into the physics of the problem beyond what has been discussed in class, etc.

2. Oral examinations: Sit at the computer workstation with the student and ask them to execute their own code, perhaps with a new set of input data. Ask the student to make specific modifications to their code in your presence, and to then compile and execute their program.

3. Short code development: Have the students write a short subroutine or modify their code under test conditions, which should include de-bugging.

4. Code development using pen-on-paper: Short tests of this sort for up to an hour are ideal. The students do not get tied up with de-bugging declaration and syntax problems. Instead, students proceed quickly to develop the core part of the algorithm.

Postgraduate studies

We do not have a separate honours programme in computational physics since our mainstream honours programme has sufficient flexibility to include computational physics modules under 'special topics', for example programming in mathematica, advanced numerical methods, scientific visualisation, etc. All students still do the core physics modules.

In addition, students are free to choose from a number of computational projects on offer each year. Depending on the availability of expertise in the department, the projects often are in the fields of fluid dynamics, solid state physics, statistical physics, cosmology, molecular physics, etc. The projects are the basis upon which students develop further skills, for example in perl programming, unix scripting, systems administration, html, postscript programming, c++, java, parallel programming, etc.

Invariably, the projects tend to be aligned with the instructors' research interests, and so real opportunities are created for computationally competent students to go on with their Masters and PhD degrees in the department. There have been, on occasion, computational physics students opting to pursue graduate studies in experimental physics – their prior computational training makes for well-rounded experimentalists.

Final remarks

A wide open niche exists for the development of undergraduate text books in the field of computational physics. Because formal teaching of this material at the undergraduate level is still relatively new, there is a dearth of good text books. This opens up a whole new field of academic endeavour for those who are interested in developing teaching materials.

Mainstream *theoretical* topics at the undergraduate level are reasonably standard at many universities, but teaching is often constrained by the need for analytical solutions to problems. For example, it is not possible to go beyond the inverse-square force field in a two-body problem in classical mechanics with a conventional chalk-on-board lecture. However, in a *computational* classical mechanics class, one can very easily change the functional form of the force field by a change to a single line in the code – and in so doing, one can consider the trajectories of a whole different set of systems.

Teaching computational physics at the undergraduate level creates a new opportunity for visiting some 'old physics' and portraying it in a new light. The students have fun, they learn useful, transferable skills and begin to see newer possibilities for studying physics.

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Appendix: Structure of the computational physics programme.

Table 1: First Year. All modules are in the major stream comprising 16 credits (180 notional study hours). The electives may be chosen freely.

1st Semester	2nd Semester
Physics I (16C) *Mechanics, Optics and Thermal Physics*	Physics I (16C) *Electromagnetism and Modern Physics*
Maths I (16C)	Maths I (16C)
Computer Science I (16C)	Computer Science I (16C)
Elective (16C)	Elective (16C)

Table 2: Second Year. The computational physics modules are primarily focused on techniques, namely mathematical, numerical programming and symbolic programming. The computational mechanics component, which is closely coupled with the mechanics taught in the mainstream physics programme, serves as a basis for introducing more advanced numerical techniques. The electives are at first or second year level.

1st Semester		2nd Semester	
Physics II (16C) *Mechanics and Modern Physics*		Physics II (16C) *Electromagnetism and Waves*	
Maths II (8C)	Elective (8C)	Maths II (8C)	Elective (8C)
Computational Physics II (16C) *Mathematical Methods for Physicists and Fortran Programming*		Computational Physics II (16C) *Mathematica and Computational Mechanics*	
Elective (16C)		Elective (16C)	

Table 3: Third Year. Notice the close mirroring of the quantum mechanics, statistical physics and solid state physics modules taught in the mainstream physics programme, and the computational quantum mechanics, computational statistical physics, advanced computational statistical physics and computational solid state physics taught in the computational physics programme. The electives are at third year level.

1st Semester	2nd Semester
Physics III (16C) *Quantum Mechanics and Experimental Physics*	Physics III (16C) *Electromagnetism and Experimental Physics*

Physics III (16C) *Statistical Physics and Modern Physics*	Physics III (16C) *Solid State Physics and Spectroscopy*
Computational Physics III (16C) *Computational Quantum Mechanics and Computational Statistical Physics*	Computational Physics III (16C) *Advanced Computational Statistical Physics and Computational Solid State Physics*
Elective (16C) *Chosen from Maths, Computer Science or Statistics*	Elective (16C) *Chosen from Maths, Computer Science or Statistics*

A PROPOSAL FOR INTRODUCING ELEMENTARY QUANTUM MECHANICS AT SCHOOL

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As a preliminary to the subtleties of quantum mechanics, many authors agree about what makes it in some sense extraordinarily simple: it is a linear theory. (R. Omnès 1999, 91)

We present the mainlines of a Project for introducing Elementary Quantum Mechanics (EQM) at school. The project aims to promote a better understanding of both the formal structure of EQM and of the main "conceptual changes" it involves. In particular, our approach to the main features of quantum formalism stems form the fact that quantum systems are *linear* systems. We will show how, by treating classical Coupled Linear Oscillators Systems (CLOS), is possible to introduce the essential aspects of the mathematical structure of EQM. On this basis, a critical understanding of the novelty of "quantum" postulates can be fostered. In order to give an idea of the main lines of our approach we will discuss an "exemplar topic": the light polarization.

The proposal

In Italy, the basic ideas of Elementary quantum mechanics (EQM) are currently taught at the end of most "Lyceum" channels. Nevertheless, student's understanding of the subject is quite far from being satisfactory. This is mainly due to the fact that both the formal structure of EQM and its conceptual meaning are presented in a fragmentary and sometimes even anecdotal way. EQM is presented as a set of calculation rules, which appear to be invented "ad hoc" in order to give a formal explanation of unusual phenomena. Moreover, it must be considered that most physics teachers have a degree in Mathematics, and thereby are lacking an adequate knowledge of EQM.

In order to improve such a situation, a teaching project on EQM has been designed at the University of Rome "La Sapienza" for the pre-service training of physics teachers with a degree in Mathematics. Indeed, the project goal is rather ambitious: student teachers, even with a poor knowledge about quantum physics, should be enabled to reasonably present the basic ideas of EQM to high school's final year students.

Obviously, the project cannot consist of a simplified and shortened version of standard university courses for physics students. These courses usually present quantum physics as a "physico-mathematical technology", with very poor attention to its conceptual meaning. Recent research has in fact shown that physics students are left with serious misconceptions and misunderstandings about physical interpretation of quantum mechanics formalism (Styler 1996, Johnston *et al.* 1998).

In our opinion, an EQM course for school students should have wider educational goals. In particular, much attention should be paid to:

- the conceptual difference between the classical and the quantum description of physical systems;
- the explanatory power of EQM in facing fundamental phenomena of the world we live in;
- the epistemological problems involved by such conceptual change.

We are aware that quantum formalism is usually neglected in any didactical presentation because of its unquestionable difficulty. Nevertheless, in order to reach a reasonable understanding of the new theoretical framework, it is absolutely necessary to grasp its mathematical essential features. Our approach allows a “soft” introduction to these features, since it relies heavily on classical systems.

Structure of the Project

The most important idea on which the project is based stems from the fact that EQM is a theory of linear systems. However, linearity is not peculiar to quantum systems: some distinctive aspects of the formal structure of linear systems can be conveniently introduced by means of a “simple” models of classical system, that is, a Coupled Linear Oscillators System (COLS).

As a matter of fact, a dynamical state of COLS can be generally represented by a vector defined in a vector space, whose dimensionality is equal to the number of oscillators. We point out that linear vector spaces are the most natural formal environment for linear systems, and that this is true both for classical and for quantum objects. A COLS oscillates, and its oscillatory state (a vector) can always be expanded in terms of normal modes, which are a kind of “global” oscillations, each one vibrating at a proper frequency.

We remind that the entire problem of finding normal modes and their associated proper frequencies is equivalent to the search for eigenvalues and eigenvectors of a symmetric matrix.[2] It is not difficult to see that such matrix has a direct physical meaning, connected to the total mechanical energy.

[2] See, for instance, chapter 10 of the well known textbook *Classical Mechanics*, by H. Goldstein (1965).

It is interesting to notice that even for COLS it is possible to adopt Dirac's notations. Indeed, it always possible to renormalize the representative vector of the system. Every possible state of a COLS can thus be represented by a "ket" (a unit complex vector), whose time evolution is of course "unitary". It is also possible to express ordinary physical quantities in terms of properly defined scalar products.

In the following, we list the project main topics.

PART 1 – LINEAR CLASSICAL SYSTEMS

- Physical and mathematical features of linear classical systems (harmonic systems)
- The superposition principle
- From discrete to continuous systems
- Elements of Fourier Analysis
- Forced oscillations and resonance
- Applications (acoustics, oscillating circuits, optical phenomena, etc.)
- The vector representation of COLS
- Linear spaces and linear operators

PART 2 – FROM PLANCK TO HEISENBERG

- The main problems of the classical physics at the end of XIX century: microscopic vs. macroscopic, discrete particles and continuous fields
- The "discovery" of the *h* constant
- The "wave-particle dilemma"
- From Bohr's model of the atomic structure to wave mechanics and matrix mechanics

PART 3 – QUANTUM MECHANICS AS A THEORY OF LINEAR SYSTEMS

- The mathematical frame of EQM
- The physical interpretation: quantum states, phenomena and measurements

We add some comments. Part 1 can be initially presented as introduction to "oscillations and waves" physics. Only the last items are planned to represent the same systems in a new mathematical language, which presents a structural analogy with the basic formalism of EQM.

In part 2, the main physical problems which gave rise to the first non classical hypotheses are presented. Students should notice how the "crisis" of classical physics stems from "borderline" problems such as the thermal radiation and the specific heats problems (in which mechanical, electrodynamic, and thermodynamic concepts and laws must be put together). *En passant*, it is worth noticing that both these problems involve set of "oscillators". The physical role of the first quantum hypotheses can thus be appreciated as a formal stratagem to "freeze" an exceedingly large number of oscillating degrees of freedom.

The wave-particle dilemma can then be presented as a first hint to an understanding of the fact that a somewhat more radical change in classical models is needed. At last, students can be led to recognize that the basic Heisenberg's idea in outlining a new atomic mechanics was indeed to treat the atom as a set of "virtual" oscillators.

In Part 3 we introduce the main general principles of EQM. Students already know that the state of a linear system (subjected as it is to the superposition principle) can be represented as a unit vector in a proper vector space. So, the attention must be focused on the peculiar quantum postulates. First, the total energy of the system must include the fundamental constant h. Thus, it can be shown that the "stationary" states of a confined oscillating system cannot take arbitrary values of total energy. Second, the measurement process of a physical quantity involves a "discontinuous" change of the state of the system: the original state is "projected" on just one of axes of the vector space. The involved scalar product is a complex number whose square modulus corresponds to the probability of obtaining the corresponding eigenvalue of that quantity.

An exemplar topic: the light polarization

In order to show how a classical problem can be treated in a "preliminary" quantum fashion, we briefly discuss a well know experiment on polarized light from a "phenomenological" point of view. We have chosen this topic (which actually should be considered as belonging to quantum optics) because of the fact that the discovery of quantum nature of light is very often presented as one of the main conceptual changes in the transition from classical to quantum physics. In an elementary approach, which takes into account just the polarization state, "photons" can be treated as simple quantum systems, leaving aside for the moment their status of quantized electromagnetic field excitation states.

We start with a purely classical description. The system is a beam of light, propagating along the z axis and prepared in a linear polarization state. The experiment consist of measuring the initial intensity I_0 of the beam, inserting a filter whose axis forms an angle _ with the original polarization plane, and measuring the intensity I_ of the emerging beam.

In our phenomenological description, the polarization state can be represented by a vector (actually the electric field vector) in two dimensional space. Being interested to the ratio I_/I_0, we can use Dirac's notations for "normalized" states: a polarization state whatsoever can be represented by a "ket"

$|\_\rangle = \_{}_x|x\rangle + \_{}_y|y\rangle$

where $|x\rangle$ and $|y\rangle$ are the unit vectors forming the basis of our space, and $\_{}_x$ and $\_{}_y$ are *complex* numbers, such that$|_{}_x|^2 + |_{}_y|^2 = 1$.

Let the initial state be represented by $|x\rangle$. Let $|p\rangle$ and $|n\rangle$ be the unit vectors forming a basis rotated by an angle _ with respect to the ($|x\rangle$, $|y\rangle$) basis. Therefore

$|p\rangle = |x\rangle\langle x|p\rangle + |y\rangle\langle y|p\rangle, |n\rangle = |x\rangle\langle x|n\rangle + |y\rangle\langle y|n\rangle$.

It can be easily shown that the action of the filter can be described by means the "projection" operator

$\mathbf{P} \equiv |p\rangle\langle p|$

The application of **P** to the ket $|x\rangle$ yields$|p\rangle\langle p|x\rangle = \cos\theta|p\rangle$

The initial state is thus projected along the polarization-axis of the filter.
Therefore, on one side, the new polarization state is represented by the ket $|p\rangle$ (a unit-vector); on the other side, the Malus' law

$I\_/I_0 = \cos^2\theta$

is simply obtained by squaring the scalar product $\langle p|x\rangle$.

The latter result means nothing but considering the formal "QM-like" expression:

$I\_/I_0 = \langle x|p\rangle\langle p|x\rangle = \langle x|\mathbf{P}|x\rangle$

In this way, a "classical" phenomenon is described in a relatively simple symbolic form, which anticipates some essential features of the elementary quantum description of similar phenomena.

As it is well known, the evidence for the quantum properties of light becomes manifest if the intensity of the beam is very low. While measuring the intensity of the emerging light, a detector emits a discrete number of "clicks", randomly distributed in a given time interval. There is no need to change the formal structure of the description: we are only forced to interpret intensities as probabilities.

Now we must face the problem of giving the correct physical interpretation of the above quantum effect. Usually, each "click" of the detector is attributed to the "arrival" of a single photon. Then we have to answer the following questions:

- Are we allowed to use the expression "arrival" of a single photon?

- Are we allowed to consider a definite polarization state as a definite "property" of each single photon?
- Can we consider the action of the filter as the selection of the photon having the "right" property?

We are of the opinion that the answers to such questions give rise to widely diffuse misconceptions not (Lévy-Leblond 2003, Styler 1996). We point out a couple of them.

1) To imagine quantum objects as fuzzy classical "particles"

For many authors, the behaviour of the detector at low intensities shows the "particle" nature of light. By speaking of "arrival" of a single photon, many authors introduce an element of ambiguity. A student may think that each photon travels along a definite path as a localized "corpuscle". But everybody know that we cannot imagine photons (and also electrons, etc.) as classical particles. We quote from R. Loudon's "Introduction" to *The quantum theory of light* (2000, 1):

> The use of the word 'photon' to describe the quantum of electromagnetic radiation can lead to confusion and misunderstandings. […] The impression is given of a fuzzy globule of light that travels this way or that way through pieces of optical equipment or that light beams consist of streams of globules, like bullets from a machine gun.

2) To confuse superposition states with mixed states

This misconception is, in a certain sense, linked to the preceding one. Indeed, what does it means to say that a "particle" is in a superposition state? In EQM, every initial state, having been prepared by an experimental apparatus, is an eigenstate of an operator corresponding to a physical magnitude. However, for describing the whole phenomenon we must take into account what we are going to measure and the whole experimental equipment. It can happen, as we have shown, that the final conditions of the experiment force us to change the basis of our vector space and to consider the initial state as a superposition state. Then, we cannot consider the initial eigenstate (and the corresponding eigenvalue of the physical quantity) as an intrinsic "property" of the system. Nor we can consider the superposition state as a mixing of systems with different or "alternative" properties. It is worth noticing that an elementary wave description of the system avoids such difficulties. However how to explain the detector's behaviour? It is easy to see that we are led to the heart of the problem of a correct interpretation of EQM.

A brief conclusion

There is no room, in this paper, for a full report on this teaching experience, on its critical assessment, and on the evidence of its success or failure.

For the moment, we can only say the evaluation of the course is based on the teaching units for school students (each one referred to a partial topic) that small groups of student teachers elaborated at the end of the course itself. We are still analyzing all this material. However, we can say that the teaching experiment was pretty successful: the most widespread comment of our students was: “now we see what physics actually is!”. Not only, but they were led to overcome their initial diffidence about the possibility of introducing EQM at school level.

We think that this is a good starting point.

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PHYSICAL SCIENCE TEACHERS’ CONCEPTIONS OF DAILY ASTRONOMICAL OBSERVATIONS AND THEIR PERCEPTIONS OF THE INCLUSION OF ASTRONOMY WITH REGARD TO THE NEW FET PHYSICAL SCIENCES CURRICULUM IN SOUTH AFRICA

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Physical Science teachers’ conceptions of daily astronomical observations and their perceptions of the inclusion of astronomy in the FET Physical Science curriculum in S.A. were investigated through MCQ questionnaires and interviews. The interview data were analysed phenomenographically. Categories of descriptions of teacher's understandings of day and night, seasons, phases of the moon and stars reveal that teachers hold inadequate conceptions. These findings are relevant for teacher education programmes.

Introduction

Exciting and innovative additions to the new FET physical science curriculum (D.O.E., 2003), for example astronomy, particle physics, astrophysics, pose major challenges to physical sciences educators. They have to make decisions about the depths of themes and select effective teaching strategies with regards to the Outcome-Based Education (OBE). The new curriculum is expected to create greater interest in Physical Sciences and seeks to provide alternate career pathways in science. Teacher's content knowledge and pedagogical content knowledge especially in astronomy education have barely been researched in SA. A literature survey in basic astronomy and earth related concepts amongst students (Trumper, 2000) suggests that the alternative concepts in astronomy are widespread and are not easy to change. Such data is necessary for curriculum planning and effective teaching and learning in the new themes. The aim of this research was two-fold: Firstly to determine the perceptions of high school physics teachers of inclusion of astronomy education in the FET Physical Sciences curriculum and secondly to categorize their conceptual understandings of basic astronomical concepts viz. day and night, seasons, phases of the moon and planets and stars.

Physics Education links with Astronomy Education

Although astronomy is one of the oldest sciences, it has only recently been introduced in the SA school science curriculum. South Africa is a leader in astronomy research and with its new project, Southern Africa's Large Telescope (SALT), astronomy education is bound to grow. Reports of introduction of astronomy education in Northern Ireland found that learners found it interesting, different and 'related to everyday life' (Jarman & McAleese, 2000). Johansson, Nilsson, Engstedt and Sandqvist (2001) state that exposing students to modern physics (including astronomy, particle physics and cosmology) with scientific data and the right tools, enables them to explore fundamental processes in nature that were previously only accessible to scientists.

Learning physics through astronomy is that it enables students to comprehend the fundamantal laws of nature. In addition, students learning is immediate and relevant to one's curiosity about the nature of the universe. The physics concepts are clearly applicable in numerous examples in astronomy, for example "What keeps the planets revolving around the Sun?" involves both a study of mechanics and basic astronomy. Another reason relates to the use, costs and impact of technical instruments in astronomy. The new FET Physical Sciences curriculum to be implemented in 2006 features several links with astronomical concepts : Grade 10 and 11

Mechanics includes planets and their movements, astronomy and cosmology; Waves, Sound and Light includes astronomical instruments, starlight and sunlight; and Grade 12 Matter & Materials covers Astrophysics.

Methodology

The methods of data collection included a Multiple Choice Questionnaire (MCQ) and individual and group focussed interviews. Fourteen high school teachers were first given the MCQ based on alternative conceptions in Astronomy. The questionnaire covered daily observational astronomy, day and night, seasons, phases of the moon, planets and stars. There were almost an equal number of females and males with ages ranging from 22-50 year-olds. The individual and focussed group interviews were conducted immediately after the MCQ was completed. Most teachers completed a diploma in education at one of the ex-colleges of education and a few had degrees in pure sciences. The teachers taught either Physical Sciences only and/or Biology or Maths. The average teaching experience ranging from 3 years to 25 years.

A question on teacher's confidence on a scale 1-5 was included to guage teacher attitude towards teaching astronomy. The data from the MCQ were analysed for high frequency choices. The data from both individual and focus group interviews were recorded, transcribed and analysed using the phenomenographic method-a complex "hermeneutic " procedure (Marton, 1981). The object of phenomenographic research is to identify the variation in ways of experiencing something or a concept. Phenomenography describes the phenomena in the world as others see them, and in reporting and describing the variation therein, especially in an educational context. Phenomenographers are also interested in exploring "changing in capabilites" (or how concepts can be changed) which can be hierarchically ordered for understanding particular phenomena. Some capabilites are more complex then others and differences between the concepts are educationally crucial to learning.

Phenomenography therefore provides a well researched theoretical foundation to construct a framework of teacher's conceptions in Astronomy and has already found applications in Physics Education (Govender N, 1999).

Results

Teachers' attitudes during interviews were positive towards astronomy education as they felt that everyday questions can be now understoon by learners. One teacher who had previously wanted to switch to Technology teaching now said that she will remain as a Physical Science teacher. Teachers generally felt that they needed workshops to upgrade their Astronomy knowledge. But, the most confident teachers said that they can teach by consulting textbooks. The data from the confidence scale and scores obtained suggests that teachers were over confident of their conceptual understandings in astronomy education. Probing physical sciences teachers' understandings of daily observational astronomical concepts through the MCQ's and interviews confirmed most of the alternative concepts experienced by school children (Baxter, 1985), university students (Trumper, 2000) and primary school teachers (Parker & Heywood, 1998) as reported in international literature. The results are reported under the following categories.

1. Observational Astronomy

Data from MCQ

1. The sun always follows the same path through the sky in SA.					
	a. True	b. False	c. Not sure	d. don't know	
Responses	5	6	2	1	
2. The sun is directly overhead at midday in SA.					
	a. Always	b. Sometimes	c. Never	d. Not sure	e. don't know
Responses	4	7	1	2	0
3. The moon is only visible at night					
	a. True	b. False	c. Not sure	d. Don't know	
Responses	2	11	0	1	

Analysis and discussion of observational astronomy :

The majority of the sample did not know that the Sun's path changes in the sky each day. A large percentage indicated that the Sun is always or sometimes directly overhead at midday. At least two teachers did not know that the Moon can be visible during the day. Trumper (2000) noted that university students performed poorly on this question as well. The Sun's position at specific times of the day and during seasons, low in altitude in Winter and high in Summer were not observed over time suggests a lack of general observation and inquiry although skills expected of science teachers.

2. Day and Night

Data from MCQ

4. The sun goes around the earth once in 24 hours.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	3	7	2	1
5. The earth turns around on a line from the north to the south pole once in 24 hours.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	9	4	1	0
6. The moon plays a role for the occurrence of day and night.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	3	8	2	1

7. The earth moves around the sun once in 24 hours.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	4	6	3	1

Data from phenomenographic analysis of interviews

Table 1 : Category of Conceptions of Day and Night
Sun is stationary-Earth is rotating

Analysis and discussion of conceptions of Day and Night

Both question 5 and 7 confirms that some teachers still hold the geocentric view instead of the heliocentric view of the Solar System. They confused rotation of the earth on its axis once in 24 hours with revolution of the earth, one a year around the Sun. This confusion is also evident in Trumper's (2000) study with students as well. Question 5 revealed that some teachers did not know that the earth rotates on its axis from west to east once in 24 hours as they chose the rotation of the earth along a line from North Pole to South Pole. There is a uncertainty arising with regard to the use of terminologies employed by science teachers where words such as rotation, revolve and spin are used interchangeably. Parker & Heywood (1998) also found that primary school teachers descriptive language was embedded in everyday language with words such as goes around,moves about, turns being employed interchangeably in describing orbit and spin.

Although teachers do not elaborate on the sphericity and opaqueness of the earth, they are aware that due to the rotation of the earth, exposure of light by the sun onto half of the earth results in day and night. Most university students (Trumper, 2000) and high-school students (Lightman and Sadler, 1993) also hold the correct view of day/night. Baxter (1985) provides four conceptions about children's ideas about why it gets dark at night viz., conceptions of the animate sun, covering the sun, astronomical movements and orbits, and rotation of the earth.

The possibilty may exists that some teachers may hold incorrect day and night conceptions as pointed out by Baxter as five teachers in Question 6 answered that the moon has something to do with the reason for day and night. A prominent and consistent concept that emerged during interviews is teachers belief that the sun is absolutely stationary. This suggest a limited understanding of the relative motion of the Sun with respect to other galaxies.

3. Seasons

Data from MCQ

8.	In summer in South Africa the earth's south pole is slanted toward the sun.

	a. True	b. False	c. Not sure	d. Don't know
Responses	6	0	4	2
9.	In winter it is colder because the heat from the sun is more spread out.			
	a. True	b. False	c. Not sure	d. Don't know
Responses	5	6	3	0

Data from phenomenographic analysis of interviews

Table 2: Categories of Conceptions for Seasons

The Sun is closer to the Earth for Summer and further away from the Earth for Winter.
The N-pole is closer to the Sun for Summer and S-pole is further away for Winter.
The earth is tilted and revolves and the tilt changes resulting in the different seasons.
The earth is tilted and revolves. Only Summer and Winter can be explained.
The earth is tilted and revolves resulting in the different seasons.All seasons can be explained.

Analysis and discussion of Seasons

With regard to the earth's tilt, 33% were unsure about the position of the South Pole in Summer in SA. 27% indicated it slanted towards the Sun and 21% said it slanted away from the Sun. The categories of conceptions for Seasons (Table 2) obtained after interviews and phenomenographic analysis revealed five distinct concepts to explain seasons. Seasons are a yearly occurrence and although a general description of the change in seasons can be furnished, few teachers provided a complete scientific explanation of seasons. Trumper (2000) found that in three MCQ questions on seasons, only about 30% of students answered all correctly and Atwood & Atwood (1996) found only one out of forty-four preservice elementary teachers answered fully. The scientific conception that was required for seasons was based on the following : The earth rotates on its axis as it revolves around the sun.

> "*The inclination of the earth's axis causes variations in the length of the day and the angle at which the Sun's rays strike the Earth's surface. These two factors affect the amount of heat the Earth's surface receive during the day and radiates away at night and it is these variations that causes seasons"* (Dilley & Rijsdijk, 2000, p. 42).

The most common explanation for seasons cited and demonstrated in this study and others (Atwood & Atwood, 1996) is the movement of the Sun closer to the Earth for Summer and further away from the Earth for Winter. Children (Baxter, 1989) at ages 13-16 year olds gave the same reason for seasons which was the commonest followed by tilt of the earth's axis. During interviews, the sequence of cycles of seasons could be stated but only Summer and Winter could be explained, either with the variable distance of Sun to Earth or the tilt of the revolving Earth. Autumn and Spring posed a significant hurdle for teachers to explain. Teachers thus hold most of the alternative conceptions that 12-16 olds still hold about Seasons as evidenced from the categories of conceptions for Seasons (Table 2).

4. Conceptions of Phases of the Moon and Eclipses

Data from phenographic analysis of interviews of Phases of the Moon

Table 3: Categories of Conceptions for Phases of the Moon

The earth casts a shadow on the moon.
The earth blocks the moon
The relative position of the Sun, Earth and Moon.

Analysis of conceptions of Phases of the Moon

MCQ in this study showed that 57 % chose the correct option whereas 30 % were unsure that the proportion of the Moon seen on the Earth depends on relative position of the Sun , Moon and Earth.

In this study three distinct explanations were given:

i)The earth casts a shadow on the moon causing the different phases of the moon: One possible reason for holding this concept maybe related to teachers understanding of eclipses and phases of moon being the result of the same phenomena.In solar eclipses, the moon's shadow falls on the region of the earth causing total and partial eclipse giving light and dark areas. These light and dark areas maybe linked with the changing phases of the moon. This is the most common conception in this and other studies, Trumper (2000) with students and Baxter (1985) with 16 year-olds high school learners.

ii)The earth blocks the moon: The earth blocks the moon from the Sun accounts for teachers incorrect explanation of new and full moon-a commonly held alternative concept. For new moon, the Sun-Earth and Moon are in a line and teachers explained that no light from the Sun goes to the moon, as the earth is on the way and the moon appears dark. For an explanation of full moon, teachers incorrectly state that the Moon is in between the Sun and Earth and light from the Sun shines directly onto the Moon which then reflects onto Earth.

iii) The relative position of the Sun, Earth and Moon results in the different phases of the moon: The full scientific explanation for phases of the moon are caused by reflected sunlight was given by only three teachers in this study and 30%-40% other studies with university students (Trumper, 2000; Zelik et al, 1998; Bisard, et al., 1994). Physical science teachers in this study had difficulty representing the correct lunar phase for a given-earth –moon model.

Baxter (1989) noted that children developed five different ideas of phases of moon including the scientific view. These ranged from clouds covering the moon, planets casting a shadow on the moon, shadow of sun falling on moon, shadow of earth falling on moon to the scientific view that phases are a function of the relative position of the Sun-Moon –Earth and reflected light of the moon. Physical science teachers hold at least three of these concepts.

5. Planets and Stars

Data from MCQ

12. Stars are the same as planets but are out of the solar system.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	3	6	2	3
14. Stars give out heat and light and planets don't.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	4	4	1	2
15. Stars go around planets.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	4	5	2	2
16. Stars are a long way away from the solar system.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	6	2	3	2
17. Some stars are nearer and some stars are further away from the earth than the planets.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	3	6	0	3
18. The Sun is a star.				
	a. True	b. False	c. Not sure	d. Don't know
Responses	8	2	2	1

Data from phenomenographic analysis of interviews

Table 4 : Categories of conceptions of Planets and Stars

Sun is the central source of all light.	Sun is a ball of fire and limited lifespan.
Sun is not a star	Sun is a star
Sun is bigger than stars	Stars bigger than the Sun
Sun has hydrogen and helium gases	

Analysis and discussion of conceptions of Planets, Sun and stars

There are seven different conceptions related to the stars and the Sun (Table 4). The naïve conception of the Sun is a ball of fire may have come from observations of coal fire. There is evidence of knowledge of the composition of the gases in the Sun but this is not related of nuclear fusion. Another common naïve conception is that the Sun reflects light onto the stars; stars themselves are not sources of light analogous to moonlight.

The MCQ and interview analysis suggests that there is poor understanding of the distance of the Sun to Earth, size of Sun in relation to other stars, composition of the Sun and distances of stars. Some teachers thought that planets and stars are the same and some thought that planets give off light. Possible reason is that visible planets like Mars, Venus and Jupiter are seen to be shining and are thought as not reflecting light but as a source of light. Stars are also thought to be found within our Solar System. A significant percentage of teachers did not know that the Sun is just another average middle-aged star.

Conclusions and Educational Implications

The data from phenomenographic anlaysis from interviews obtained in Tables 1-4 provides crucial information of teachers' understandings of daily observational astronomical phenomena. Some of the conceptions that physical science teachers hold are not scientifically correct and some even mirror conceptions held by children. Without an intervention teachers will most likely pass on their naive conceptions to their learners. In resolving the problem, there are two major issues for teacher education and development: First teachers need to improve their own concepts through the acquisition of declarative knowledge focussing on the phenomena they are to teach, and; second, teachers need to know how to present astronomical phenomena at an appropriate level using their pedagogical content knowledge.

Teachers therefore must be aware of the alternative conceptions that they themselves hold and must experience the necessary conceptual changes to be effective with their students.The categories of conceptions obtained for the different astronomical phenomena in this and other studies provides us with this knowledge. Since teacher's conceptual knowledge influences the way learners perceive and make sense of knowledge (Appleton, 1992), teachers must also be aware of their learners' conceptions at a particular age or school phase level and acquire knowledge of how to resolve them. Moreover, if teachers' content and pedagogic content knowledge is not firmly resolved, conceptual confusion will occur at both teacher and learner level.- a serious issue for teacher education.

Research must now also focus on teaching strategies to match local conditions in classrooms. Thus we must learn more about resources and cultural influences that assist teachers in resolving both their conceptual difficulties and those held by their learners. This should include teachers discussion of alternative concepts through active learning (Comins, 2000), interactive groupwork, use of interactive CD's and video's and using three-dimensional models, for example, using torches, spheres of different sizes and scaling of the Solar System.

This study thus contributes to the initial understanding of astonomical concepts of physical science teachers and cognizance must be used in conjunction into other studies that also address curriculum development issues in the Physical Sciences.

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LEARNER DEVELOPMENT THROUGH SCIENCE CLUBS

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A method of learner development is examined whereby a network of learners, educators, scientists and the government contribute toward the establishment of learner-run school science clubs. The contribution of these science clubs to the development of valuable life skills, which are otherwise not necessarily taught, is discussed. An implementation plan is also proposed that could lead to the establishment of a national network of science clubs.

Introduction

The idea of establishing science clubs, both in primary and secondary schools, is not unique. The benefits of such a club to the learners involved are quite obvious and have previously been recognised. The method described here, aimed at maximising the benefits that clubs can offer, involves the networking of learners, not only with each other, but also with the local (and international) scientific communities as well as with governmental bodies. Co-operation and participation of science-related organisations in school and regional science club activities can result in a giant leap forward in the promotion of science and technology. Learners feel that they are part of the science community through communication with real scientists doing real, world-class science.

This science club network should also include governmental education departments already concerned with developing learners. The result of the extensive networking project could lead to greater excitement surrounding science and technology, which leads to an increase in participation of learners in science club activities, which naturally leads to the learners from these clubs developing numerous skills, not only within the realm of Physics, but also in terms of organisation, leadership and communication.

The beauty of having such a structure in place, namely a network incorporating organised bodies from school to scientific to governmental levels, is that students, teachers, government representatives and practicing scientists will be able to communicate. In the same way, the science clubs in schools can give concerned adults feedback from the learners concerning the state of education, possible grievances and suggestions for improvement. This channel that reaches down to the learners themselves would be invaluable to the increased effectiveness of any effort by any party aiming to promote an interest in science and technology.

The effectiveness of this approach relies on the premise that within every school there are at least a few learners who are already motivated and interested enough in science and technology to be able to participate actively in a science club. These learners should be identified by the co-ordinating educator and given the tools to launch such a club. They would then naturally start developing the leadership and organisational skills required of the leaders of any organised body. As their club grows, more learners would become involved in projects and together they would also develop scientific, cognitive, financial and entrepreneurial skills. Introducing these clubs to each other and to the local science-related industries results in further development of communication and teambuilding skills. Such clubs would facilitate the development of various other project-specific skills among learners, which could be advised by the education department of the government and researchers in science education.

Skills Development:

The greatest contribution of science clubs to the education of a learner is the wide variety of skills that it provides them with. Whether the learner pursues a career in the world of science or the world of business, science clubs prepare them with skills for the real world environment. Most of these skills cannot be taught in a classroom environment and those that can are more effectively grasped through participation of the learner in a body such as a science club. In order to examine the various benefits to learners, let us look independently at scientific, entrepreneurial and other project-specific skills respectively (although it must be noted that many of those mentioned below do overlap).

Scientific Skills

There are many useful skills that can be developed through a learner's participation in a science club. One of the most obvious and basic skills is that of independent research. Almost all projects undertaken by the science club needs to be well researched before implementation. This would entail a feasibility study and research into previous similar work. The next step during a science club activity would be project planning, an invaluable skill needed in the scientific workplace. Inevitably, there would also be the need for documentation, which is an essential skill required by a scientist. These documents would take the form of funding proposals to sponsors (should their project need a budget) and letters of motivation to superiors (to obtain permission from educators for certain activities). There would also be the reports that need to be compiled after the completion of the project and the proper filing and recording of this information.

As the network grows, there will also be large-scale events such as exhibitions and inter-school science club conferences that need to be organised. This type of organisational skills is extremely useful to a scientist due to the importance of conferences in the scientific community.

The networking and collaborations between different clubs from different areas will also train the learners to deal with different people and improve their communication skills. A scientist always needs to be able to communicate well so that he/she can establish and maintain scientific collaborations with other people in similar fields.

Entrepreneurial Skills

Since many of those learners who study science at school will never enter into a scientific career, it is important to examine the benefits to the average business oriented career. Perhaps the most apparent of skills to benefit this career path is the organisational one. Anyone involved in business needs to have a good sense of how an organisation works and the basic principles of working within and running such an organisation. Involvement in a science club would equip a learner not only with the experience of being part of an organisation but also the skills required to run one.

They will learn about organisational structure, how to perform the election of officials, how to prepare for and co-ordinate regular meetings, the basic activities performed during a meeting such as chairing and minute keeping, and how to maintain a filing system with records of your meetings and activities. The learners will also inevitably learn about the subtle issues such as the politics within an organisation and the part that human relationships play under certain circumstances. The other very useful skill is in the handling of finances and budgeting. As these clubs grow so will the size of their projects and thus the size of their budgets. Managing these budgets trains the learner in the management of not only the budget of a business but also his/her personal income during his/her employed lifetime. Depending on the nature of the club, there will also be the need to advertise or run campaigns for certain issues. This will develop the learner’s marketing skills, an invaluable part of businesses today.

Project-Specific Skills

Since learners generally find it easier to communicate with their peers than with educators or parents, one can use the science clubs as a means to develop skills that may not be developed in a classroom environment. For example, if a science club holds a competition that requires cognitive skills, e.g. brainteasers, then fellow learners would participate more enthusiastically than they would if it was a problem given by an educator in a classroom. Other examples of skills development projects are:

- Bridge building/Construction competitions which would develop skills in design and engineering
- Demonstrations of scientific concepts would help develop experimental skills
- Tours to science-related institutions would educate learners on current activities taking place around the world

- Problem solving challenges and competitions build cognitive and/or mathematical skills

- Forum discussions on interesting topics improve the learners' communication and interpretation skills

- Mini lectures given by the science club to the rest of the school improves their teaching and presentation skills

- Student exchange programmes develop the learner to interact with and learn about other cultures and societies

This list could be extended by the government education departments and researchers in education in order to incorporate and optimise targeted developmental areas.

National Implementation:

The following steps are suggested for the national implementation of a network structure that would support this method of learner development.

a. Perform survey of schools and scientific institutions: Basic survey needs to be performed to obtain contact details of schools and scientific institutions around the country. Government departments should be approached for assistance in this regard.

b. Establish contact with scientific institutions: The plan of action needs to be communicated to as many scientific, engineering and industrial institutions as possible and feedback must be used to establish a list of participants.

c. Establish contact with tertiary institutions: A similar list of participating universities and technikons must be determined – contact must especially be made with science faculties.

d. Establish contact with schools: Letters need to be sent to as many schools and teacher bodies as possible detailing the project in simple terms. These letters should urge the formation of a science club by expressing the willingness of local scientific institutions to collaborate with the school. Also included should be suggestions for small projects, which learners could use to start themselves off. Schools should also be given contact details of participating institutions in their area for times when they need support.

e. Perform follow up investigations and provide support to the clubs: Tertiary, scientific and industrial participants should be asked to check up on the schools' science clubs in their respective areas.

f. Facilitate inter-school activities: Once these clubs have been formed, facilitate projects that involve the collaboration of all or some of the participants. These may include:
   - Inter school science fairs
   - Visits to tertiary and scientific institutions
   - Student exchange programmes
   - Visits by professional scientists
   - Visits by tertiary students from different fields
   - "Lending Libraries" for sharing of laboratory equipment and texts
   - Collaboration with regard to updating school syllabus
   - Science club conferences

   All these and other activities should be aimed at uniting these clubs and arousing greater interest in science through the enjoyment of shared activity.

g. Major Event: In order to create maximum awareness of science and technology and to give these clubs something to look forward to, an event should be held that incorporates all of the participants on a regional and/or national basis. This celebration of science and technology should form the culmination of all efforts up to that point. A well laid out infrastructure of science clubs will guarantee that the celebration reaches every corner of the country in a very visible manner. An example of such an event would be a student component of the celebration of the World Year of Physics 2005.

Anticipated Outcome:

The science clubs would be established and run by the learners themselves (with the assistance of educators) and would need minimal support and guidance from the scientific community. Once a few motivated young learners take over, they would naturally embark on the task of promoting science and technology in their respective environments. This task would result in the development of numerous skills that would otherwise never be acquired at school level. As more young people learn about science and start to enjoy it, the teaching of Physics and other science-related subjects would become easier and more effective.

The established network would serve as a channel of communication whereby educators and researchers could obtain direct information concerning the state of Physics education through interviews with representatives of such societies. This information would be used to further improve the teaching of Physics. The embedded activity of promoting science and technology would result in greater interest in science-related careers, which addresses a major problem currently being faced by the science community. At worst the learners who become involved in these science clubs will develop scientific and entrepreneurial skills and gain greater exposure to the world of science.

PHYSICS FOR TEACHERS

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The design of the physics curriculum for the new Bachelor of Education at Wits University is described. The majority of students taking the course have a poor entry-level science background. The course addresses the science needed for teaching the new South African curriculum in schools, but goes beyond to the 'big ideas' in modern physics, with emphasis on conceptual understanding rather than mathematical manipulation. Examples are given of the contextualised approach which is used to make classical physics concepts accessible to students. The course includes the socio-political context of nuclear power; sustainable development; the cost of energy; indigenous knowledge systems; the nature of science; learners' persistent unscientific ideas; race and gender issues; and laboratory and study skills. Central to the course design is the constructivist methodology used. At the start of each topic, students are given an exercise to elicit their existing ideas about the topic. Students are given many opportunities to 'talk science', in interactive lectures, and in small group work. A weekly tutorial period, where students work in assigned mixed ability groups, has provided essential scaffolding for weaker students. Apart from the formal practicals, apparatus is used extensively – to demonstrate phenomena, and for hands-on group work and circuses. Strategies for assessing student performance line up with the broad aims of the course. The course is a work in progress, but thus far students have responded well, both in how they feel about the course, and in their performance.

Introduction

What physics do secondary school science teachers need to know? This question was tackled in designing the physics curriculum for the 'Physical Science in Education' course for the four year Bachelor of Education at Wits University, which started in January 2003. Pre-service physical science teachers on the course will do the equivalent of Physics I and II, over four years, with an average contact time of four 50 minute periods per week (including practicals). The design of a course involves more than content, it also involves the methodology used in presenting the course, and the means of assessment. In this paper, I present the rationale behind the content, methodology and assessment choices which I have made.

Key to my approach are my beliefs about how people learn – my concept of 'need' in my opening question is coloured by my paradigm. My educational philosophy is constructivist: students come to a physics class with their own ideas which interact with the ideas which the lecturer presents, and, as a result, students construct their own meanings from classroom experiences. Research reveals that, even after instruction, students hold persistent unscientific ideas or misconceptions, in many areas of physics (for example, Helm, 1978). However, learning experiences in which students are actively engaged with the subject matter are more fruitful than situations where students are passive.

Challenges

The major obstacle is the poor entry-level science background of the majority of the students taking the course. These students would not be accepted into a B Sc course based on their school results[3]. They have typically never worked with apparatus in science lessons, and have been taught by teachers who are not qualified in science. As a result, they rely heavily on rote-learning, and have inadequate problem-solving skills. There is also a sprinkling of students from privileged school backgrounds. The challenge is to make the course accessible to all, and at the same time provide stimulation for the more capable students.

A second challenge arises from the fact that some students in the group are specialising in primary school teaching, and do only a half-course in physics (one year).

Course Content

Topics

In selecting the content of the course, consideration was given to the knowledge which teachers need in order to be able to teach the new South African science curriculum, as embodied in the National Curriculum Statements (Department of Education, 2002 & 2003). This curriculum has a strong emphasis on science in society, i.e. science in the context of socio-economic issues. One of the unifying statements for the Energy and Change theme is:

> Energy is available from a limited number of sources, and the sustainable development of countries in our region depends on the wise use of energy sources. (Department of Education, 2002, p. 66)

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[3] Entry to the Wits B Ed course is by matric with exemption, with a minimum of 12 points, or by an access test. To specialize as a science teacher, a minimum of 60 % for Mathematics Standard Grade is required. The average point count of the 2004 first year physics class is 16,7. By contrast, 28 points are needed for automatic admission to the Wits B Sc.

Thus one lesson in the course explores the concept of sustainable development and examines the links between environmental problems and our consumerism. In an assignment, students are required to evaluate the claims made in an advertisement for energy-saving compact fluorescent lamps. Students also calculate the cost in Rand of the energy needed to run their household appliances. The R-9 National Curriculum Statement refers to the degradation of energy in energy transfers, and so the 'spreading' of energy arising from the second Law of Thermodynamics is explored. Students draw energy flowcharts to show the flow of energy in their homes.

Pedagogical content knowledge and teaching methodology are integrated into the course. Students are made aware that research exists about persistent misconceptions in mechanics and electricity. Once in a while, students discuss a 'concept cartoon' (Naylor and Keogh, 2000) which shows learners discussing a topic, illustrating the unscientific ideas which teachers may encounter in the classroom.

However, while teachers need the basics for teaching, it is not enough for teachers to only know about school science, and thus all of the 'big ideas' of modern physics are covered (fig. 1). In the first year, students are introduced to special relativity and particle physics, while big bang theory and quantum mechanics are dealt with in later years. The mainstays of classical physics are also covered.

The results of research by Lederman and Lederman (2004) suggest that the Nature of Science needs to be taught explicitly. Attention is also paid to gender and race issues, for example the role of women in cosmology is explored, together with the way this role has been subverted in history. Students do the Draw-a-Scientist-Test, and then reflect on their conceptions of scientists, and consider the impact this has on how they view their learners in the classroom.

Figure 1: Topics

Physics I	Physics II
▪ Mechanics	▪ The Nature of Science
▪ Special Relativity	▪ Mechanics
▪ Radioactivity and Particle Physics	▪ Thermodynamics
▪ Geometric Optics	▪ Electromagnetism
▪ Current Electricity	▪ Electrostatics
▪ Heat	▪ Fluids
▪ Circular and Rotational motion	▪ Electronics
▪ Vibrations and Waves	▪ Light
▪ Sound	▪ Quantum Mechanics
▪ Electromagnetism	▪ Cosmology
	▪ General Relativity
	▪ Particle Physics

The Role of Mathematics

Physics is more than mathematics: explaining a concept is more than merely modelling the concept mathematically, and the ability to manipulate equations to get the right answer does not prove understanding. For example, when, in the context of a discussion on types of forces, I ask first years 'What causes gravity?', their answers typically refer to the atmosphere, the spin of the earth, or the earth's magnetic field. Yet all of them recognise and are able to use the equation for Newton's Law of Universal Gravitation, which clearly relates gravitational force to mass. I thus aim to develop conceptual understanding rather than mathematical competence.

Moreover, since the mathematical ability of the first year class is generally weak, and since not all the first years study mathematics, I avoid clouding the physics unnecessarily with mathematical noise. The first year course does not even use trigonometry - instead of traditional force vector problems, students apply Newton's laws to situations where the resultant force is in either the x or y direction. However, by third and fourth year, students are expected to use the calculus they have learnt in the mathematics course – the use of mathematics is delayed rather than omitted.

Contexts

Real-life contexts make physics attractive and accessible to students. In kinematics, students measure their own reaction times, then calculate stopping distances for vehicles, and consider the effects that speed and alcohol have on these distances. To develop their understanding of the socio-political context of physics, the first years role-play a town meeting to decide whether a nuclear power station should be built near Vereeniging. For one of their practicals, students visit a nearby playground, and do experiments on the merry-go-round (rotational motion and angular momentum), the swings (pendulums) and the slide (energy conversions). In a module on cosmology, students research the indigenous knowledge which their families have about stars and the moon. The first years do a module on Jobs in Science (GDE/GICD, 2000) in which an interview with a herbalist is acted out, following which students discuss the question "In what ways does a herbalist work scientifically?".

Where suitable, I take students to interesting sites on campus and beyond. For thermodynamics, we visit the Technika section of the college, to look at actual two and four stroke engines. When dealing with the wave nature of matter, we look at electron diffraction on an electron microscope. Students visit NECSA at Pelindaba, the Hartebeeshoek Radio Astronomy Observatory, the Schonland accelerator, and the new Sci-Bono science centre in Johannesburg.

Skills

Along with most physics course designers, I aim to develop appropriate laboratory skills in my students. It is particularly important that future science teachers are comfortable using physics apparatus. In the new school curriculum, school learners are expected to be able to design a 'fair test' for a hypothesis, and thus it is important that their teachers also have such skills. Accordingly, most formal practicals are presented as a contextualised 'problem to be solved', rather than a 'method to be followed'. The limitation of this is that the solution to the problem is closed: ultimately the students have to go with the solution which corresponds to the equipment provided. Thus the second year students are given a completely open-ended investigation, where each pair has to pose their own question (for example, ‘How does the initial temperature of popcorn affect the volume of popcorn produced?’), and design their own method, with variables suitably controlled.

There are other skills that students need in order to succeed in a physics course. Students from enriched educational backgrounds usually have these skills, but students from disadvantaged backgrounds are often unaware of the need for such skills. To provide the scaffolding to help such students, I have developed a series of handouts on ‘Skills in Science’, based loosely on the Biology skills course developed by Osberg (1997). These include ‘What should I do between science lectures?’, ‘The Physics Textbook’ and ‘How do I prepare for a Physics Test’. I distribute these one at a time during the first teaching block, integrated with the course.

Methodology

I aim to model good teaching practice in my lectures, for two reasons. Firstly, this is the most effective way of improving my students’ knowledge and understanding of physics. Secondly, I want to role-model the kind of teaching methodologies that I would like my students to use in their classrooms – when I watch them teach at local schools, I want to be able to criticize them with integrity. In addition, students have different learning styles, and the use of a variety of strategies caters for different students.

Constructivist Approach

In line with my constructivist beliefs, at the start of each new section, students are given an exercise to elicit their existing ideas on the subject. Sometimes students work in groups to make a summary of what they know, in the form of a mindmap or table. For electricity, the students use copper wire, cells, light bulbs and sellotape to demonstrate how they would wire their uncle’s shack. For heat and for fluids they work through a circus of small experiments which they try out and discuss. These sometimes use the ‘Predict-Observe-Explain’ approach (fig. 2). At the start of dynamics, students answer a few questions (designed to bring

Apparatus	• 1 spring balance with 200 g mass piece attached • Beaker with water
Predict …	***Before*** *you do the experiment, decide what you* ***think*** *will happen.* **What will the spring balance read when …** • the mass piece is hanging in air? • the mass piece is suspended in water?
Observe…	Try out the experiment: 1. Suspend the mass piece from the spring balance, and read the weight of the mass piece. 2. Hold the spring balance so that the mass piece is suspended in the water in the beaker. Read the spring balance.
Explain …	• **Explain** your observations. • Draw a free body diagram for the mass when it is in the water.

out their misconceptions) individually, and then try to reach consensus on the answers, first in pairs, and then in groups of four. Each opening exercise is used as the starting point for discussion of the topic at hand. My strategies for different topics are informed by the literature on misconceptions research, as well as by what I have learnt from students.

In addition to the hands-on experiences described above, I am committed to demonstrating physics phenomena in lectures wherever possible. Sometimes a demonstration provides a discrepant event, which challenges the preconceptions of the students, and provides the cognitive dissonance which they need in order to revise their existing schemata. For example, I construct a capacitor (without naming it) from tinfoil and paper, and ask the class whether current will flow when I connect it to a battery. The students are certain that current will not flow. I then demonstrate that current *does* flow briefly when I connect the battery, which leads into a discussion on capacitance. The practical experiences during 'lecture' periods are usually qualitative, compared to the quantitative approach of the formal practicals.

Group work

The wide range of ability of the first year group has provided an opportunity for peer teaching. For the tutorial period, the class is divided into mixed ability tutorial groups, where students help each other, and teamwork physics and chemistry questions which they could not manage individually. This provides students with opportunities to 'talk science', to see how successful students work, and to learn strategies from each other. The tutorial groups have proved to be an important pillar of the first year course, and nearly all the students report that they have found the tutorial groups useful:

> "[My tutorial group] helped me a lot. I felt free among them, like to ask questions, and have some input where necessary. I can say it boosted my self-esteem."
> "Sometimes I understood better from my group than my lecturer."

As already indicated, small group work is regularly used during the 'lecture' periods. Typically the students are given worksheets which give information and require the students to act on that information in some way. In radioactivity, students are given a selection of seeds, and a worksheet which gives them information on nuclear decays and requires them to model the decays with seeds. At the end of a section, a period is sometimes set aside for students to work on a 'goal free' exercise (Hobden, 2001). For example, the first years are given the 'collisions in two dimensions' apparatus and a metre stick, and asked to calculate everything they can for the two balls. After rotational motion, students are given a turntable with two coins on it and a stopwatch, and asked to work out every quantity they can for the two coins.

Even in a more formal lecture setting, I often throw out a question which students are required to discuss ‘with the person sitting next to them’ before giving feedback - this gives more reticent students the opportunity to make their contribution.

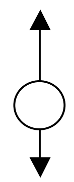
Assessment

In the eyes of students, what counts is what is assessed. If only calculations and mathematical manipulation are tested, then students will devalue all else. Thus calculations generally count for less than half the marks in the tests and examinations for the course. Questions are included where candidates are required to explain concepts, or discuss the teaching of topics at school level (fig.3). For calculations, I avoid questions which simply require students to plug values into a formula. Since their rote-learning skills are already well developed, students are not required to

4. Thandi throws a ball up. She draws a free body diagram for the ball, after the ball has left her hand.

4.1. **Explain** why Thandi’s diagram is incorrect. (2)

4.2. What is the **unscientific idea** which Thandi has about forces? (2) [4]



(June 2003)

Figure 3: Sample Exam Question

rote-learn derivations; rather I occasionally set unseen derivation questions.

The traditional register of scientific discourse can complicate the science unnecessarily, so I am careful to ask questions in simple English. The allocated time for tests is generous: speed should not be unduly emphasized in assessing the abilities of science teachers, as they get faster with practice in the classroom anyhow.

Student Response

Students have generally responded favourably to the course. The first year group participated in a Student Evaluation of Lecturer Performance in the middle of 2003: the score was in the top 10 % range for medium-size classes at Wits. Student written responses to open ended questions about the course have mostly been positive, and reflect consistency between my aims and how students perceive the course.

> “The way our lecturer presents a new topic to us, she makes it really interesting, by maybe acting out a certain situation or by doing a practical experiment.”
>
> “She gives us a chance to think independently. She acknowledge each and every answer a student gives.”
>
> “A person like myself personally, I wasn’t confident with my capabilities doing physics, but under your proper guidance I’m a star.”

And, importantly, despite their poor entry-level science, most students are succeeding in passing the first year course: in 2003, 47 out of 54 students passed the course - those who failed included two students who were absent for significant periods.

Conclusion

The design of the course is still a work in progress. Only the first one and a half years of the course have been taught, and I have made revisions this year based on my experiences with the first year course last year. Ongoing student feedback will provide input for further revisions. However, the favourable response of the students thus far suggests that the approach employed could be used more broadly. Although I am fortunate to be working with relatively small groups of students, the strategies I describe are not restricted to small groups: Fakete and McInnes (1997) report using the Predict-Observe-Explain strategy with large lecture groups at the University of Sydney. The facilitation of peer teaching in structured tutorial groups is also a useful strategy for large groups.

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IS THIS THE KIND OF PHYSICS EDUCATION THAT ENCOURAGES STUDENTS TO STUDY PHYSICS?

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The South African educational system is in a phase of fundamental change, moving from a curriculum based on highly specified content based syllabi for each subject in the curriculum to a new outcomes based curriculum in which the development of skills and attitudes has been given equal prominence to content. This change will have a significant effect on what physics is taught and how it is taught at school in preparation for higher education. However, many are not sure as to the value of this change perhaps because they are not aware of what we are proposing to change from? The purpose of this paper will be to reveal what students actually experience when learning physics in grade 12 under a prescriptive syllabus and high stakes national external examination. To answer the questions an interpretive method was used based on a year-long observation of two physical science classrooms.

Introduction

The South African educational system is in a phase of fundamental change, moving from a curriculum based on highly specified content based syllabi for each subject in the curriculum to a new outcomes based curriculum in which the development of skills and attitudes has been given equal prominence to content (Department of Education, 2002). However, there are many within the physics teaching profession who are not happy with this development. For example there are those who value the present system and don't want significant change but would rather focus on teaching what we have, more efficiently. There are also those who would change to something completely different with a focus on skills and a minimum of prescribed content. Given these conflicting calls it is important for decision making to know what is happening in our classrooms. What is it we are proposing to change from?

When searching for answers in the research literature, it becomes apparent that there is a lack of South African detailed case study or qualitative research, providing detailed descriptions of students' experiences of learning physics. Even recent studies such as Taylor and Vinjevold (1999) and Ntshingila-Khosa (1994) do not provide the detail required to understand what the studying of physics at school really involves. The purpose of this paper will be to reveal the kinds and qualities of experience students have when learning physics in grade 12. It will contribute to our knowledge base, and inform the debate in curriculum reform.

The physical science curriculum for grades eleven and twelve is described in an official education department document circulated to all schools and referred to as the syllabus (KZNDEC, 1995). This document outlines the main aims of the school course and the requirements for the senior certificate examination that takes place at the end of grade twelve. Teachers are given considerable detail as to what should be taught and what skills should be developed. For example, it explicitly states that students must be able to perform calculations and solve problems using equations that are specified. In the section on the kinematics topics, this syllabus states that students have to "perform calculations" and that evidence of higher abilities requires students to use their understanding in "unfamiliar situations" (p.18). Similar use of formulae and calculations exist in other countries.

In addition, high schools have a long history of working in a centralised high-stakes examinations system. This is an external examination organised by the Department of Education and commonly referred to as the "matric" examination. In physical science, the students write physics and chemistry examination papers of two hours each. The examination is competitive, in that it ranks students by performance, and allows the more successful students to proceed to tertiary study. It seems possible for this matric examination to subvert the published curriculum, in that what we test and how we test is the one way in which a de-facto curriculum is defined (Schuster, 1993).

Research Approach

The following focus question was constructed to guide and frame the study. *What is happening in physical science classrooms?* The question is associated with a number of sub-questions, which were useful in moving focus from the general to the particular: What do the teachers do?; What instructional strategies do they use?; What do the students do?; What tasks do they engage in?; An interpretive method (Gallagher, 1991) starting with a detailed descriptive foundation obtained through classroom observation was chosen as the most suitable strategy for describing and understanding what was going on.

To obtain the detailed information required to answer the questions, the study was limited to two physical science classrooms in different schools in which I was a participant observer for most of a school year. Jack and Susan (the two teachers who participated) were chosen to participate in the study because their schools were reasonably accessible, they were experienced science teachers and they were willing to participate. The multiple data sources included field notes from over a hundred classroom visits, extensive video and audio records, questionnaires, classroom documents and formal and informal interviews with teachers, students and examiners.

The participants

Susan Smith was an experienced science teacher having been teaching for over 10 years. The grade twelve class that was observed had 28 students and was multicultural in composition, containing a number of English second language students. The school was situated in a middle class urban area but also drew students from nearby lower class areas. Physical science was taught for four hours per week during three double periods and a single period. The vast majority of the students passed the final senior certificate examinations but few obtained good results or higher grade passes.

Jack Jones taught in a large middle class urban school. The Grade twelve class of 32 students while multicultural had very few students whose home language was not English. The class had five sessions of physical science per week, totalling about 4 hours. In the final examinations over ten of the students obtained an "A" for physical science while only one or two failed to achieve a pass at the higher grade. Most were taking 6 subjects with a typical package being English, Afrikaans, Mathematics, Physical Science, Geography and Art. Many took a "double science" i.e. doing both biology and physical science. During the year about 110 hours was spent on physical science of which about half is physics. The topics covered during the grade 12 year were Newton's Laws, gravitation, work energy and power, electrostatics and electricity.

The findings

The following empirical assertions represent knowledge claims about patterns and regularity found in the data. These assertions were obtained from the case study of Jack and Susan's classroom data through a process of careful and systematic analysis. Unfortunately due to length restriction examples of the supporting evidence is not presented except in outline. The detailed warrant for the assertions is provided in the report of the full study (Hobden, 2000a).

The problem tasks as part of instruction

1. <u>*Activities with a focus on the solving of problem tasks occupied about three-quarters of all available time.*</u>

Physics teachers have a responsibility to provide a learning environment in which the students can develop the desired skills and understanding set out in the syllabi. To achieve this many different types of activities are possible. However, a detailed examination of the use of teaching time in both cases gives convincing evidence that few types of activity were used and the solving of problem tasks were the focus of teaching and learning for most of the available time.

For example in Jacks class at least 70% of all time involved students explicitly solving a problem task or being shown how to solve a task. This included about 20% of time on tests that were almost exclusively problem tasks. Other tasks included practical work (5%) direct teach-ing of concepts (20%) and general administration (5%). The evidence was overwhelming that for students, doing physics was associated with doing "problems". For example in student interviews in which they were asked to describe their science lessons to a visitor from another country one student said: *"I would say science is just basically you've got a lot of formulas you have to know, you have to learn and you've got a lot a problems to work out, you know, to do with equations*". In answer to "*so what do you do everyday in this class*" the answer was "*You work on problems. We spend time working different problems out*." Even the progression through the syllabus work was frequently referred to, by both teacher and students, by means of the number of the particular problem task that was currently under discussion such as "electricity worksheet problem four".

2. *The students encountered a large number of problem tasks during the year. The majority of the problem tasks were specific to a syllabus topic, were uncomplicated and were routine in nature.*

A common characteristic of both classrooms was the fact that the students encountered a large number of problem tasks, or as one student in Jack's class said "millions of problems", which they had to solve. In virtually all situations, the source of the problem tasks was the worksheets, the end of chapter textbook exercises, class tests or past and present examination papers. For example the number of problem tasks in one of the classes for the three sections of physics was: 45 in Newton's Laws & Gravitation, 57 in Momentum, Work, Energy & Power and; 86 in Electrostatics and Electricity. The vast majority of the problem tasks were specific to a syllabus topic such as electricity or gravitation. Within each physics syllabus topic, there were clearly identifiable sets of problem tasks that were similar to one another. They were identified by three main characteristics: they were formulated using similar problem situations; they required the same set of principles and formulae to solve and; they could be normally solved within 5 to 10 minutes. Analysis of the problem tasks revealed two main types of situations. Firstly, many of the problem situations were similar to the following:

> Two trolleys, A and B are moving under frictionless conditions in the same direction along a horizontal line. Trolley A has a mass of 4 kg and moves with a velocity of 5 ms^{-1}. Trolley B has a mass of 2 kg and moves with a velocity of 1 ms^{-1}.

They are what I call "skeletal situations". It appeared that they had been specifically designed to have no obvious link to recognisable real-world events or objects. The second type of situation is represented by the following problem situation:

A golf club exerts an average force of 3 kN on a ball of mass 0,06kg. The golf club is in contact with the ball for 5 x 10-4 s.

I refer to these as "stripped" situations. While there were direct links to everyday objects and events, they were uncomplicated situations, with no extraneous information and were stripped of all real world complexity and ambiguity.

3 *The majority of the routine problem tasks were quantitative in nature requiring the simple one or two-step application of a formula or principle for solving. They were of low conceptual demand.*

I identified six basic responses that were most frequently asked for. These were: recall of definitions; construction of a graph or diagram; calculations requiring the use of formulae; qualitative description or explanation; interpretation of data, formulae or graphs; and application of a principle to predict an event. However, over 90% of all problem tasks required students to respond by the simple one or two-step application of a formula or principle to calculate a numerical answer.

Very few tasks required students to provide descriptions, explanations or interpretations of data. In addition the majority of the problem tasks encountered by the students were routine in nature. This indicates that by the time they encountered the majority of them in tests, they should have been relatively easy problem tasks with low conceptual demands being made on the students. For example, in the following excerpt from an interview with a learner, I had asked him to account for the fact that he had found a pulley problem relatively easy to solve on the test: *"we've done so many examples, …there's a whole worksheet full of them… and when once you've done one, you remember the rest…. and just basically apply the same formula, you know, over and over again".*

4. *Students found the repetitive solving of these problem tasks boring.*

There was overwhelming evidence that the majority of students found this instructional focus on hundreds of problem tasks to be boring. For example, in an open-ended questionnaire, given to students in which they were asked to describe what they did in science each day, more than half of the students expressed negative sentiments about the daily activities and the term "boring" or "bored" was frequently used somewhere in their description. For example when students were shown a video recording of a lesson in which Jack was explaining how to solve a problem and asked to comment on their actions, a number of students gave negative written responses such as:

"Boredom - nothing interesting. Monotonous - nobody paying much attention. Too repetitive and boring to hold anyone's interest. Going over a simple question in too much detail. It almost puts me to sleep".

Teaching students to solve problems

1. *In order to teach their students to solve problem tasks the main components of the strategy were teachers explaining how to do it, students practising on similar problem tasks and learning from their mistakes.*

Consider a typical example of how Jack dealt with a problem task by explaining how to do it. He would identify the relevant physics principle e.g. conservation of momentum, followed by the formulae associated with the problem situation, and then apply them in a structured way on the board while providing a commentary containing a qualitative description. Student involvement was to "watch" and supply information when required, such as data extracted from the problem statement or answers to numerical calculations. Not all students participated, with the majority not asking or answering questions during these performances. Reference to the hundreds of problem tasks used, makes it obvious that practice at doing problem tasks played an important role in both teachers' instructional strategy. This perception was reinforced by comments such as the following made by Jack "*It is as Gary Player says, 'The more you practise the luckier you get.' Some of you kids need to listen to Gary Player."* Both Jack and Susan saw value in carefully going over the solutions to problem tasks after the students had attempted them. One of the expressed reasons for this was for the students to learn from their mistakes.

2. *Jack and Susan encouraged their students to use both general and specific problem solving strategies.*

Susan and Jack modelled and encouraged their students to use two types of strategies. The first, was a general strategy used to understand the problem task as a whole and was used across all topics and types of problem tasks. Jack used an envisioning strategy. He was always emphasising the need to "project yourself into the problem and imagine what is happening". This resulted in many of his explanations having a qualitative component, with time spent on understanding the task qualitatively before moving onto application of the formula. Susan's approach was to appeal to common sense and to "just think about it". Added to this they often emphasised the use of logic and reasoning. A specific part of this general strategy was to draw a diagram, which they themselves would do when explaining how to solve the problem. The second strategy was a specific set of instructions, hints or tips that were specific to particular types of problem task such as a pendulum situation. As each topic was encountered with its sets of similar problem tasks, Jack and Susan would demonstrate how to solve these types of problem task following a particular method or solution path. As indicated earlier, these routine problem sets were very similar and the situation would normally cue the formula or formulae to be used. They would provide particular hints and tips for the different routine problem types. Susan also followed a more structured approach emphasising a specific numbered set of instructions such as writing information down, what are you asked to find, select a suitable equation, change the subject of the formula, substitute and solve.

3. *Students were able to solve routine problem tasks but were not able to deal with the difficult problem tasks.*

The question of whether the instructional strategies used by the teachers were successful is a difficult one to answer. This is because there are many interpretations or perspectives from which success can be viewed. If the purpose of the strategies was to end up with students who could pass a specific examination, Jack's strategies could be considered very successful (eight students obtained distinctions) while Susan's would not be as successful (many only achieved between 40 and 50%). However, when it came to more difficult problem tasks the picture was depressing. In Susan's class virtually all students were unable to solve the difficult problems while in Jack's class only a few students could. It was obvious that the strategies they were taught were ineffective for all but the routine problem tasks. Students were aware that these more difficult problems would appear in their tests and examinations. For example, when I questioned one student about his performance on a test, he replied, "*I found the questions to be more challenging than those we do in class. The ones in class are pretty simple and then when we get a test they always seem harder.*" The above yields a picture of the dominant mode of teaching how to solve the problem tasks being for the teacher to explain and model how to solve them, followed by student practice on similar problem tasks. In their modelling, of how to solve problems teachers encouraged students to use strategies. Unfortunately, this approach was not effective in teaching the majority of students how to solve anything but the routine problem tasks (Hobden, 2000b).

Conclusions

Given the stated goals for the science curriculum, there appears to be both an imbalance and overemphasis on the use of problem tasks to achieve the syllabus goals to the disadvantage of other aspects of physics. It would be no surprise if the students gained the erroneous impression that physics was only about solving problem tasks. The descriptions and assertions provided construct a picture of school physics education that is less than satisfactory. The instructional system has failed to achieve what we desire for our students (Van Heuvelen, 1991). There is little emphasis placed on developing conceptual understanding of the scientific concepts.

This situation is not what we would desire for our physics classes. The implication is that many students will continue to leave school with a set of beliefs about physics that are not consistent with those we would hope to promote (Hammer, 1994). Students will not see physics as a coherent system but rather as a series of isolated topic items with the content of physics being lists of definitions and formulae, rather than the structure of concepts and principles that underlie them. Problem solving will be viewed as dealing with routine problem tasks rather than a higher-order skill. In addition, this heavy emphasis on problem tasks led to students finding the school subject of physical science boring.

While there may not necessarily be consensus about what the physics curriculum should look like, there is convincing evidence from the current study and others that a curriculum based on mastering a corpus of facts and procedures to solve routine problem tasks is severely impoverished. Because current practices engender a skewed view of what physics is all about, there is a need to change what is taught and learnt and how it is taught and learnt (see Hobden, 2003). We need to design instruction carefully, based not only on what we know about what it means to do physics, but also on what we know about learning.

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VISUAL MODELS IN THE LEARNING AND TEACHING OF ATOMIC PHYSICS

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Modern Atomic Physics was developed long after Classical Mechanics, which mostly deals with macroscopic observable entities and processes. It is much easier to visualize the observable classical mechanical entities and processes than none-observable entities and processes in the world of atomic and quantum physics. This article presents a study probing into the problems of visualization as experienced by students and lecturers of atomic physics. The consequence of limitations with the visual learning and teaching strategy leads to a rote learning approach. The research results suggest more consideration of visual aspects by textbook authors' utilization of technological developments through development of computer software for interactive simulations.

Introduction

In his response to the question **"What physics should we teach?"** Richard Feynman could have expressed the importance of atomic physics in relation to the human culture as follows:

> If all of scientific knowledge was to be destroyed, and only one sentence to be passed on to the next generations, the statement that would carry most of the information in the fewest words is the atomic hypothesis. The fact that all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another (Feynman 1963, p. 4)

Feynman believed that there is an enormous amount of information about the world in the previous statement, if just a little imagination and thinking are applied.

Atomic physics deals mostly with objects, entities and processes that are not directly observable with human senses. The development of atomic physics is marked by ideas that sometimes seem to violate common sense. This branch of physics considers things and events that are orders of magnitude in physical dimensions removed from everyday experience. It is its 'remote' nature that contributes to students' problems to visualize atomic concepts and ultimately to understand this important section of physics and chemistry.

Visualisation is an important faculty of learning and teaching (Perkins 1991, White 1988). Visualization here refers to forming mental images and using such images for understanding. Despite the obvious importance of visual images in human cognitive activities, visual representation remains a problem in the teaching and learning environment (Hesse 1966, Holman 1975, Kuipers 1969, Smit and Finegold 1994).

Description of the study

The research was done in the context of attempts to identify the ability of first year students to visualise in atomic physics and to probe into their lecturers' awareness of the importance of visualisation and the extent to which they utilise the visual teaching strategy in their classes. The information obtained from these objectives was used to draw conclusions about conceptual barriers with regard to visualization experienced by students in understanding atomic physics. Information was obtained by means of two questionnaires: one for students and one for lecturers. The information was supplemented by interviews with students after the questionnaires were administered. The research was conducted on a population of 289 students enrolled for first year courses in physics at the University of North West and three of its affiliated teacher training colleges and 10 lecturers presenting atomic theory at these institutions.

General findings and analysis of results

General findings in analysis of results in students' questionnaire

The questionnaire for students consisted of 26 items of open and close-ended questions. Students' responses were grouped and analysed in the following seven categories:

- <u>Descriptions/ Definitions</u>

  In terms of the Bloom's taxonomy (Bloom 1956) on the cognitive domain, definitions and descriptions belong to the first level (and least abstract) of the six levels of abstraction in learning. This level deals with *knowledge* and it involves among other key actions, rote recall of previously learned facts. In this survey respondents were to respond to the following questions: *what is an atom?, what is an electron?*

The majority of respondents describe an atom in terms of its size. 62.6% regard it as the smallest part of matter. As with the study conducted by Ben-zvi (1990, p. 188), it is also proved in this study that students who view an atom as the smallest piece of an element will encounter serious conceptual difficulties when studying particle physics, which deals with the subatomic world.

A remarkable impression on students about the atom is the 'spherical' or 'bag' model. 48.4% of responses displayed the 'bag' model, as they believe that the constituent parts of an atom are held together in a bag. Textbook phrases like "*an atom contains….*" (Cutnell and Johnson 1998, p. 911) may lead to the misconception that an atom is surrounded by a kind of shell analogous to that of oranges in a bag.

A conclusive remark is that students have a fairly good perception of both the atom and the electron. Students' descriptions of these two entities and definitions correspond mainly with those given by textbooks in the lower grades. The expression that *the first impressions are everlasting* proved to hold truth in the learning of new concepts. The indivisibility of the atom seems to be indelible in students' minds and the earlier fact that it is the smallest particle. Definitions are indeed memorized and a permanent impression is made by students thus leaving little room for new facts as may be discovered later.

- <u>Pictorial interpretation/representations of verbal information</u>

A high percentage (78.9%) of students claiming to have mental pictures of given statements was in contrast with a lower percentage (33.2%) for acceptable sketches drawn of such models indicate a lack of clear mental models. The results with the Bohr model also indicated a high percentage (50.9%) of students having mental pictures and only a lower percentage (19 %) could sketch acceptable pictures.

The range of scientifically unacceptable mental pictures held by students on different atomic models (*Thomson's', Rutherford's, Bohr's and de Broglie's*) based on the given statements indicates a general inability in attaching scientific acceptable mental pictures to verbal statements and /or a lack of clear mental images of an atom.

Analogies proved to be useful in explaining the invisible processes of the atomic world. As seen from the responses on the Thomson model and the Rutherford model, a high response (77.5%) was obtained for Rutherford's model, a factor that could be attributed to the familiarity with the analogy used, compared to 33.2% acceptable responses for the Thomson's model.

Only 22.5% of the students produced acceptable responses where students were to represent a picture of Bohr's postulate of an *electron jumping to a higher energy level after absorbing a photon.* The results indicate a general difficulty that students have in representing dynamic processes in terms of sketches.

Another remarkable observation is the poor visualization for quantum mechanical atomic models from given statements. The responses on the visualization of the early atoms indicate 33.2% and 77.5% acceptable responses for the Thompson and Rutherford's model respectively while obtaining lower responses for the transition model (Bohr's) and the modern atomic model as proposed by de Broglie. The responses were 19% and 9.3% for the two models respectively.

- <u>Verbal interpretation/representation of pictorial information</u>

Given two types of information on the same concept, i.e. some information given in words/verbal form and the other in pictorial form, students perform better on the pictorial information. 41% of respondents could identify Bohr's postulate as represented by a picture while only 22.5% could sketch an acceptable picture of the same postulate from a given statement. A further confirmation of this assertion is the 19% acceptable sketches of the Bohr model based on a given statement in another part of the questionnaire.

A conclusive remark is that for this group of students a *pictorial-to-verbal conversion* of information is easier than the *verbal-to-pictorial conversion.*

- <u>Description of given statements in own words</u>

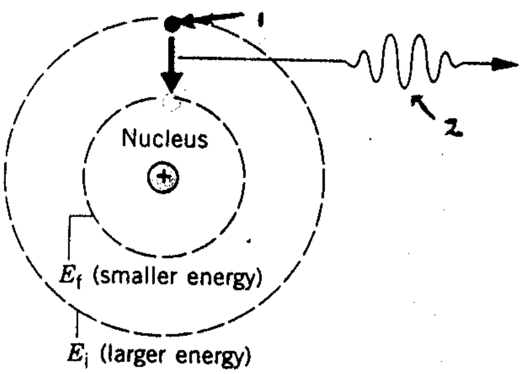
Description of statements in own words is at the second level of Bloom's taxonomy (Bloom 1956) of cognitive domain. It tests for *comprehension*, which is a more complex and more difficult level of learning to attain than *knowledge.* In this survey, students were required to describe the following postulate: *An electron in an allowed orbit does not radiate* in their own words. The fact that only 17.6 % gave acceptable results from a scientific perspective implies a serious deficiency in comprehension that may be due to poor vocabulary.

- <u>Labelling of components of given statements</u>

As with definitions and descriptions, labelling of components is also a lower (first) level of learning in terms of complexity. It belongs to the knowledge category of the Bloom's taxonomy of cognitive domain (Bloom 1956). The research results indicated a good response of students to labelling the parts in a given atomic process. 75.1% of the group produced correct responses for the electron and 60.2% for the photon.

- <u>Mathematical representations of given statements</u>

Students displayed difficulty with mathematical representations of physical processes**.** The Figure below was correctly identified by 41.2 % of the respondents as representing Bohr's postulate 3.



This postulate states: *When an electron jumps from one orbit to another, it emits or absorbs a photon whose energy is equal to the difference in the energies of the two orbits*. Students were requested to write a mathematical expression for the energy of the photon (label 2). In spite of 60.2% who correctly identified the photon and 75.1% who identified an electron in the given diagram, only 31.5% of respondents wrote the correct equation of the energy of the photon as stated in the postulate. This assignment belongs to the third level of Bloom's taxonomy of the cognitive domain (Bloom 1956) that requires *application* of knowledge and facts acquired in mathematics in a new situation.

A conclusive remark based on this research is that students are in general less able to apply knowledge. They are less able to do an *application* than at displaying *knowledge.*

It should be noted that the acquisition of knowledge could be through rote learning methods.

- Students' opinions about pictorial representations and functions of models

22.8% of the respondents indicated their problems with pictorial representations as lack of clear mental pictures or a clear imagination. 15.6% regards interpretation of statements as the main hindrance to pictorial representations. The other 22.8% regard making pictures of unfamiliar objects as the main difficulty. The later response could imply on students' reliance on rote learning methods. Three- dimensional representations are also identified in this study as being difficult to students.

It is clear from the study that students involved in the study did not have a clear historical conception framework of the developments in atomic theory. Such a historic framework brings into effect the role of models in science, and models as subject to change upon receiving more and new evidence. Students' 'actual models' of an atom indicates a tendency to have a permanent impression of the early atomic models (e.g. Thomson's) even after exposure to the quantum mechanical atom.

General findings in analysis of results in lecturers' questionnaire

The lecturers' questionnaire consisted of 31 items of open ended and close ended items, followed by interviews probing into their difficulties as well as their strategies in teaching atomic theory. Information about students' learning strategies was also acquired. General findings emerging from an analysis of the results of the items from the lecturers' questionnaire were grouped into the following five categories:

- Importance of pictorial representations and mental images

The majority of lecturers (90%) instruct their students to form mental pictures of concepts in atomic theory. They all regard a combination of verbal description and mental pictures as important in the learning of concepts in atomic theory. 70% of the respondents make sketches when explaining atomic concept, but 70% find it difficult to make good 3-dimensional sketches on transparency or board. 90% reported that their students find it difficult to interpret sketches of 3-dimensional objects. All lecturers expressed difficulty in representing dynamic processes.

- Learning strategies of learners

Literature reveals different learning patterns by students (Driver 1986, p. 443: Kaluszynska 1995, p. 85). Some patterns are common among rote learners while others are characteristic of meaningful learning (Ausubel 1968). In this survey 70% of the lecturers regard their learners as relying primarily on rote learning methods.

- <u>Use of and acquaintance with analogies</u>

  Lecturers tend not to use analogies in explanations and it appears that they do not know what the concept analogy is.

- <u>Assessment of students mathematical ability</u>

  Lecturers rate students' mathematical ability as better than their science concepts. Mathematics to most students is learned by following 'procedure' and crunching the numbers.

- <u>Issues related to reading</u>

  Lecturers do not read on issues related to science education in spite of the presence of relevant journals in their institutions. They generally believe that journals are for studies towards a qualification only. They also do not attend courses/workshops on student learning. This reflects a deficiency in professional growth and impacts on their knowledge and skills related to visual aspects of teaching and learning as they are ignorant about the latest developments related to this topic.

Conclusion

The research results indicated awareness of visualization as an important aspect in the learning and teaching of atomic physics. The lack of the necessary skill to utilize this faculty in the learning and teaching processes as expressed by both lecturers and students is to be considered in curriculum development for educators training. The research results suggest more consideration of visual aspects by textbook authors and a renaissance of interest in visualization that should be driven to a large extent by technological developments through the development of computer software for interactive simulations.

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DESCRIPTION OF A COURSE FOR SECONDARY SCHOOL PHYSICS TEACHERS THAT INTEGRATES PHYSICS CONTENT & SKILLS

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In this paper we will illustrate how the materials for a course were designed in order to incorporate the development of four categories skills of Physics teachers. The categories skills are cognitive, metacognitive, teaching and experimental skills.

Background

The course Physics for Teachers I and II is a certificate course aimed at teachers currently teaching Physical Science for Grade 10 – 12. The program was designed with two broad objectives: To develop the teachers' understanding of Physics content as well as to develop their pedagogical content knowledge (PCK). According to Shulman (1987),

> ..many teachers have weak understanding of specific content in their disciplines and lack clear representations of how to teach important concepts

Because we are a distance education institution we designed the program in order to make the study material relevant so that the teachers can use it in the classroom interactively and make a difference in their teaching and learning. The teachers don't have to be taken out of their classrooms and leave their learners unattended to.

One of our aims when compiling the study material was to embed the teaching of skills in specific content by intertwining the content and skills, and not treating them as separate entities. Implicit in our use of the term "skill" is the notion that it is something that can be learned by the student and improved with practice, rather than something a student either has or does not have. (Grayson, 1996).

In order to design our study material we looked at what skills are needed in Physics.

- According to Arons (1979, 1984, 1990) some **thinking and reasoning skills** required in physics are: to distinguish inferences from observations, distinguish an influence from a determining factor, formulate and test hypotheses, make appropriate approximations, interpret abstract representations, e.g. graphs, equations, translate between physical phenomena and representations, give phenomenological explanations, recognise limits of applicability of models/theories, perform proportional reasoning, perform hypothetico-deductive reasoning, reason by analogy and generate a logical argument.

- According to Schultz & Lochhead (1991) **problem solving skills** are: To organize quantitative calculations through an understanding of qualitative relations, represent a problem situation via diagrams or drawings, organize one's knowledge according to principles that bear on the solution of the problem at hand, and evaluate the validity of a provisional physical (or other) model through an analogy or chain of analogies.

- According to Grayson (1996) some **experimental skills** needed in physics are: to manipulate simple apparatus, take accurate measurements and record them correctly, make correct and careful observations, analyse and display data appropriately, control variables and design experiments. (Note that many of these skills are not restricted to physics.)

- According to Nickerson (1985) examples of **metacognitive skills** have been identified as, planning, predicting, checking, reality testing and monitoring and control of one's own deliberate attempts to perform intellectually demanding tasks.

Description and Examples

When designing the study material the following skills were addressed:

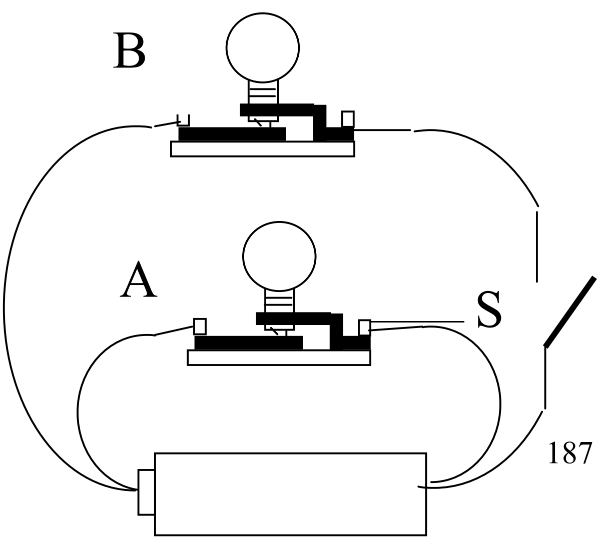
- Teaching skills
- Experimental skills
- Cognitive skills where reasoning and thinking skills as well as problem solving skills were addressed in particular and
- Metacognitive skills

The following teaching skills were incorporated when designing the study material: drawing of graphs, diagrams & sketches, listening & questioning, problem solving, using specific teaching strategies, designing experiments, using incorrect answering of learners, using simple apparatus, interpreting abstract representations, stimulating learning as a group activity, using correct terminology, teaching for conceptual understanding, discussing of concepts often taught incorrectly, explaining of using techniques to resolve forces, setting problems to develop problem solving skills, applying physics in daily life, involving learners in experimental work, using predictions to expose current understanding, facilitating conceptual change where there are misconceptions and emphasizing the responsibility of a science teacher as a citizen.
To illustrate how the content and skills have been intertwined the following two examples are given and discussed.

(In the rest of the paper the following abbreviations will be used: Reasoning and thinking skills as (RT), Problem solving skills as (PbS), Experimental skills as (ES), Teaching skills as (TS) and Metacognitive skills as (MS).)

Example 1

The teachers were asked to look at the following circuit. Bulb A is connected to the battery and will be lit. They were asked to predict and explain what would happen to the brightness of bulb A when switch S is closed (see the diagram). They had to do the investigation in order to see if their prediction was correct.



A common misconception amongst learners when they have to give answers on parallel circuits is: *"When the switch is closed the current is shared by A and B, so the brightness of A becomes less"*. The experimental results contradict this answer as the brightness remains (nearly) the same. A discussion about this incorrect reasoning of using "currents only" was included in the study material.

The teachers were also asked to draw a standard circuit diagram of the above representation.

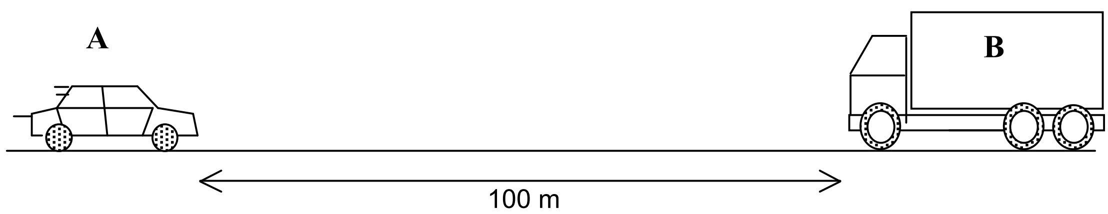
In this example, RT, ES, TS and MS were addressed as explained in the following:
Their reasoning and thinking skills were investigated in the prediction. They had to perform hypothetico-deductive reasoning and generate a logical argument.

In performing the experiment their experimental skills were developed by manipulating the apparatus, taking measurements, making correct and careful observations as well as analysing the data. To check if their prediction was correct, they used their metacognitive skills by predicting and checking the brightness of the bulb, and then they did reality test after performing the experiment versus their prediction. In this way they can monitor and control their own attempt to perform an intellectually demanding task.

The teachers' teaching skills were also developed by using this teaching strategy to teach for conceptual understanding and follow the discussion of concepts often taught incorrectly. By asking the teachers to draw a circuit diagram their reasoning and thinking skills were developed once again because they had to translate between physical phenomena and representation.

Example 2

The drawing below shows two vehicles approaching each other. Let us call the time for this situation t = 0,0 s. Car A moves with a velocity of 15 m/s and the velocity of A is constant. At t = 0,0 s truck B starts to move from rest with an acceleration of 1,5 m/s^2.



a. When and where do they meet?
b. What is the velocity of A and the velocity of B when they meet?
c. Draw the x-t graph of A and B in one diagram. Check whether your answer found in (a) is in agreement with the graph.

d. Draw the v-t graph of A and B in one diagram. Check whether your answer found in (b) is in agreement with what the graph shows.

The students can check the correct answers at the back of the Study Guide.

In example 2 the following problem solving skills were developed. The teachers have to organize quantitative calculations through an understanding of qualitative relations, as well as represent the problem situation via diagrams or drawings. They also have to organize their knowledge according to principles that bear on the solution of the problem at hand.

In answering (a) and (b), the following reasoning and thinking skills were developed. They have to translate between different kinds of representations as well as translate between physical phenomena and representations. However in answering (c) and (d) they have to plan, check whether their answer was in agreement with the graph, do a reality test and monitor and check their own deliberate attempts to perform this intellectually demanding task.

Conclusion

In this paper we have illustrated how in addition to develop content knowledge a variety of skills have been developed in the Physics for Teachers module. The study material intertwines the content and skills in a very effective way and according to one of the students when reflecting in his journal, *"I have developed an understanding of the difficulties pupils experience in studying work and energy and I have acquainted myself with a number of teaching strategies that I can use"*.

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PHYSICS EDUCATION RESEARCH: A CASE STUDY OF CURRICULUM AND INSTRUCTIONAL DEVELOPMENT FOR NON-TRADITIONAL, RE-ENTRY, ENGINEERING STUDENTS

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Physics education research (PER) spans a wide range of situations from physics courses for preservice teachers to calculus-based courses for physics or engineering majors and illustrates the use of a diverse range of innovations. PER results consistently indicate that what students learn from many traditional introductory physics courses does not often match the instructors' expectations. When physics instructors and departments undertake curriculum and instructional reform they must begin the process of redesigning programs or courses to better align expectations and outcomes for a specific course and the student enrolled in the programme. The central focus of this study is: How can the wide range of PER results be used in the curriculum development process for a specific course by physics instructors whose main focus is not physics education research? A general model for curriculum development is proposed with various choices to adapt the curriculum for specific students, programs and goals.

A case study of two introductory physics courses in an access program to engineering technologies was used to illustrate the curriculum development process. The group of non-traditional students in these courses presented a wide range of academic skills resulting in significant challenges for curriculum and instructional development. Historically the success rate for the access program was 25%. The objective for a revised curriculum was to improve retention of academically weaker students while maintaining the positive elements of the original program. A new introductory physics curriculum was implemented that included the original topics in a more flexible learning environment. Emphasis was placed on students' conceptual understanding and the development of skills necessary for academic success in later courses of the engineering technology programme. A feedback mechanism was used for developing a model of learning, curriculum development, instruction, and research in a helical improvement cycle. Results from this study indicate that setting realistic objectives, implementing a curriculum that has been designed for specific students and collecting data for feedback in a spiral of improvement, leads to a better match between faculty expectations and student outcomes.

Introduction

Why has physics education research (PER) made so little impact on many, if not most, introductory physics courses? A review of the literature for PER reveals a wealth of information and results applicable to curriculum and instructional development for introductory physics courses spanning a wide range of situations from physics courses for pre-service teachers to calculus-based courses for physics or engineering majors and illustrates the use of a diverse range of innovations.

Most research papers start with statements about how little learning occurs in traditional introductory physics courses and that what students learn does not often match the instructor's expectations. At some point, physics instructors and departments come to a decision that curriculum and instructional reform is necessary. When this realization occurs, they must begin the process of redesigning programs or courses to better align expectations and outcomes for a specific course and the students enrolled in the course. But attempts to select newly-published papers of particular significance for the university physics teacher has become a difficult task." (Holcomb, 2002, p.1).

A selective review of PER literature (McDermott & Redish, 1999) included over two hundred research papers that represent a starting point for physics instructors whose teaching expertise is necessary for effective instruction (Hake, 2002; van Aalst, 2000).If the curriculum for most introductory physics courses is used for comparison, the idea of teaching and learning physics does not appear much different now than it was 50 or 100 years ago. The vast majority of textbooks provide overwhelming evidence that not much has changed in 100 years: 20 or 30 chapters of 19th century physics taught as the basic knowledge necessary for advanced studies in physics. But this assumption is faulty since fewer than 10% of the students enrolled in introductory physics courses continue to obtain degrees in physics.

The message of better ways to teach the traditional physics curriculum dominates PER literature. Examples of changing and expanding the curriculum to meet the needs of 21st century students are limited and have not had significant effect. Thus, a paradox exists between physics departments, where faculty think that fundamental, classical physics is important for all students, and the majority of students whose interests are peripheral to the focus of most introductory physics courses. Lijnse (1998) suggests that curriculum reform in the past has been limited by lack of adoption of 'the spirit' of the reform and the problem may be one of 'dealing with curriculum-proof teachers.'

Redish (1996) describes an interactive mechanism for curriculum development, McDermott's wheel, based on results from the Physics Education Group at the University of Washington, where PER, curriculum development and implementation and feedback data are used in a helical spiral of improvement. Using this idea a flowchart has been created that can be used to integrate PER results, program objectives, course goals and objectives, curriculum topics, curriculum implementation, and student and faculty feedback in the helical spiral of improvement. The use of a wider range of instruments over many cycles of a course may result in introductory courses that are a better match to the stated outcomes of the courses and the outcomes for students enrolled in those courses.

Introductory Physics Courses: Research Results

Research has shown that traditional curricula and instruction do not have a significant impact on the majority of students undertaking introductory physics courses (McDermott, 1991). While most physicists would agree that science literacy for all students is desirable, the focus in most introductory physics courses is on analytical problem solving and understanding the concepts of classical topics. Many introductory survey courses cover 30 - 40 chapters of typical textbooks. Results from numerous studies indicate that taking an introductory physics course may not have any significant impact on a student's conceptual understanding. These results do not consider that students may not even be exposed to the nature of physics, its historical development, and role in society. With a few exceptions, introductory physics courses are filters in "a 'pipeline' through which students pass on their way to science careers" (Costa, 1993, p. 649). In spite of the fact that the vast majority of students will take no other physics courses, physics professors are reluctant to consider reducing coverage to increase depth of understanding or to replace traditional topics with alternates that are not considered as basic to understanding physics. This has been termed the 'structure of the discipline' problem in curriculum development (Lijnse, 1998).

In most physics classes, the objective is to provide students with sophistication in the application of mathematics to physics. However, there is an increasing awareness of addressing beliefs and attitudes in introductory physics courses. If changing understanding and attitudes of students are goals of introductory physics courses, then it is necessary to know what conceptions and attitudes are prevalent among the entering students. Most introductory physics courses are service courses for non-physics majors. Students in these courses have attitudes, perceptions, and mechanisms that conflict with instructors' goals (Elby, 1999). It appears that the physics education system is structured to accommodate the perceived needs of the physics community rather than the needs, goals, and prior knowledge of the students. This has, and will continue to put physics departments at risk in most teaching colleges and universities.

Osborne (1990) discussed the "articulation of a rationale for why we teach physics" and that "values and aims are essential for considering what is appropriate to the process of … teaching and learning." Heller (2004) and Heller et al. (2004) described a process for setting such goals, which included questions of whose goals should be considered, the state of students' conceptual understanding, students' misconceptions and skills in physics and mathematics, and the instructor's pedagogical skills and misconceptions. Further questions relate to the course structure: lectures, tutorials, laboratories, co-operative work, etc., and the reality for making change. Priorities and decisions require that designers question how much change is possible, the necessary and available resources to implement realistic change, and the processes in place to acquire data for feedback and quality assurance.

Case Study of Physics Courses in Access Program (Engineering Technology)

This report of a curriculum development project involves physics courses in an access program (one year) leading to an engineering technology program (two years) at a community college. There were very limited prerequisite requirements for admission to the access programme. The group of non-traditional students enrolled in the access programme presented significant challenges in curriculum and instructional development due to the wide distribution of student attributes. No research studies apply specifically to this group. Historical results from the Access Program were reviewed and data were collected to document the students' cognitive and affective attributes. The attrition rate for this program had been 75% yet for the remaining 25% of students the program was judged to be very successful. The objective for this curriculum development was to improve retention and learning for academically weaker students while maintaining the positive elements of the original program that had proved successful.

The purpose of the Access Program was to provide opportunities for students without formal educational backgrounds to obtain, over three terms of work, prerequisite credit necessary for admission to a two-year technology programme. The age range of students was from 18 to 42 and more than 70% of the students had been away from formal educational environments for more than two years; 40% for more than 10 years. Within a class, between classes, and in different years there were wide variations in the types of students. Mathematics knowledge was hypothesized as important for academic progress in physics. On a test of algebra based on the British Columbia curriculum for Mathematics 8, 9 and 10 the average pre-course score was 44% with scores ranging from 10% to 86%. Results from a pre-course application of the Force Concept Inventory (FCI) were much better than published results (Hake, 1998). The range of scores on a 30 item FCI was from 13% to 97% with an average of 54%. This near the upper limit for students in introductory physics courses, including calculus-based courses. Thus on average the students appeared to have strong conceptual understanding of physics but poor mathematics skills and due to the length of time away from formal education many of the students did not have strong study skills. Thus the challenge in delivery the physics course curriculum was adapting to the many different requirements of the students.

Two sequential introductory physics courses were modified from existing, traditional, university level, algebra-based courses. A consideration in planning the new course was to focus on class activities that would be beneficial to weaker students and thus reduce the wide distribution of academic results and high attrition. A goal of the revised program was to reduce the high attrition rate. The first change for one group of students was to delay the physics courses to the second and third term, providing students with the opportunity for review of mathematics background material in their first term of studies. The alternate groups were enrolled in their first mathematics and first physics course concurrently.

The physics courses' curricula were modified to reflect constructivist ideas while retaining the major part of the original, traditional curriculum. An instructional model was developed that included non-traditional components based on results from PER, students' prior performance and beliefs and faculty perceptions about goals for the program and about the students in the courses. The program was evaluated over two, three-month terms of the program. The instruments chosen and the interpretation of the data were planned to provide robust descriptions that could be used for regulating future curriculum and instruction for other, possibly different, groups of non-traditional students.

Curriculum Development Process

A flowchart can be used as a guide for curriculum development to expand the process to include questions about a program and course with the flexibility to include parameters that apply to a specific group of students.

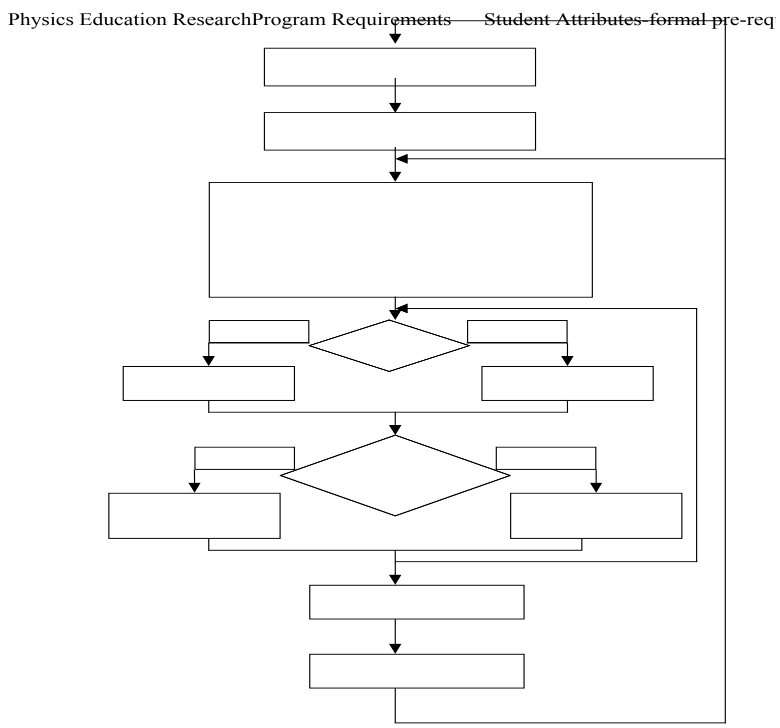

Figure 1: Flowchart for curriculum development

The use of this flowchart (figure 1) encourages faculty to ask questions about the course goals and the relationship of the goals to the students enrolled in the course. For many faculty and physics departments, curriculum development is a short-term event. The use of feedback data and reevaluation of the outcomes of a course in relation to the original goals should be an ongoing part of a standard model.

Each of the individual steps in the flowchart appears as obvious. For example, models and examples are readily available for setting goals and outcomes. Yet, for many courses, the goals and outcomes may be undefined and restricted to traditional topics. In using this flowchart faculty will be forced to evaluate the course in terms of broader goals, relate the course outcomes to students in the course, and promote a long-term curriculum development process.

The Case Study for Access Students: Use of the Curriculum development model.

The Access Program included the prerequisite courses for an engineering technology program. As a consequence, and due to external restrictions on changes to the physics courses, the topics for the physics courses were from the traditional areas of classical physics. The goals for the new courses were to better adapt the course content to the prerequisite knowledge and skills of the incoming students, while maintaining the academic level so that students who completed the access program would experience success in the subsequent courses of the technology program. While alternate measures of success were discussed, traditional testing was retained as the dominant form of evaluation. Major changes to the courses occurred in the instructional environment where ideas from constructivism were used for greater flexibility in the pace of learning and for more emphasis on student engagement in the learning process compared to the traditional lectures that had been used.

Data were collected from the students before and during the physics courses and used to define their academic state. These and additional qualitative data collected during the courses were used to evaluate and modify the model of instruction. The results for this group of students indicated that pre-course mathematics skill was the most important factor for success in physics. While the instructional environment improved attitudes to physics, as measured by the Maryland Physics Expectation Survey as well as qualitative data from journals, the retention rate for the program was similar to the historical rate of 25%. However, the attrition rate for those students who were in the course sequence with one term of mathematics before their first physics course was lower than the rate for the alternate group who undertook mathematics and physics in their first term. The non-homogeneous nature of the data from this study makes data analysis difficult. Data from subsequent years is necessary to draw statistical conclusions.

Closing Remarks

In traditional introductory physics courses, the curriculum has most often been based on typical textbooks and instructional methods have been based on the views and experience of the instructor. PER has shown that this has not achieved remarkable results, but has also provided the means for improvement from descriptions of many innovative instructional methods. Setting realistic objectives, redesigning curriculum and collecting data for course evaluation can be used in a spiral of improvement to provide a better match between expectations of faculty with actual outcomes. The use of a curriculum development flowchart can broaden the focus of the curriculum development process. In evaluating goals and objectives, collecting qualitative and quantitative data for feedback may make physics departments and instructors more aware of the relationship between the curriculum and student outcomes than has been the case in the past. A number of instructional cycles are necessary to evaluate the efficacy of the curriculum and instruction.

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A UNIT ON OSCILLATIONS, DETERMINISM AND CHAOS FOR INTRODUCTORY PHYSICS STUDENTS

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As part of the activity-based *Workshop Physics* curriculum developed for calculus-based introductory courses, we have developed a unit on oscillations and chaos that provides a capstone for the study of mechanics. We discuss the unit and its major themes which include the viability of Laplacian determinism, the use of numerical integration to model data, and chaotic behaviour.

Introduction

Many contemporary fields of physics require a knowledge of quantum mechanics or relativity. For this reason introductory courses rarely give students any real insight into emerging fields of research. The fact that non-linear dynamics is almost entirely classical in nature provides students first hand exposure to an active field of contemporary research. For this reason, we developed a unit on *Oscillations, Determinism and Chaos*[1] as a culminating experience for calculus-based introductory physics students as they complete the mechanics portion of the *Workshop Physics* Curriculum.[2,3]

The *Workshop Physics* Project

The *Workshop Physics* Project began in the fall of 1986 with a grant from the Fund for Improvement of Postsecondary Education (FIPSE). Additional support from FIPSE and the National Science Foundation (NSF) allowed us to complete an Activity Guide, computer hardware and software, and apparatus that enable students to learn without lectures. The major objective of *Workshop Physics* courses is to help students understand that physics involves an interplay between observations, experiments and the construction of theories.

Instead of spending time in lectures and separate laboratory sessions, students in calculus-based *Workshop Physics* courses centre their work on an Activity Guide. The Guide contains 28 units covering topics in mechanics, thermodynamics, electricity and magnetism, and nuclear physics.

Students typically spend 6 hours a week in a lab environment, and are able to complete most of the units in two semesters.

The Role of the Oscillations, Determinism and Chaos Unit

Oscillations, Determinism and Chaos[4] completes a series of 15 units that cover Newtonian mechanics. Most of the lab work in the unit on chaos involves recording and analyzing the motion of a physical pendulum that is made increasingly complex until it becomes chaotic.
In previous units students do mathematical modeling by using the dynamic graphing capability of Excel® to match their data with analytic functions (linear, quadratic, inverse, and sinusoidal). The chaos unit requires students to model more complex systems using the Euler method for numerical integration. Because an overarching goal of the unit is to explore Laplacian determinism, it provides a philosophical and theoretical capstone to mechanics.

The Chaos Unit

The key apparatus consists of an aluminum disk mounted on the shaft of a rotary motion sensor. When a small mass is bolted to the disk edge and displaced from equilibrium, the system becomes a physical pendulum (Fig. 1a). Adjustable eddy damping is added by means of a small neodymium magnet (Fig. 1b). Finally, students combine strings, springs, a driver motor, and eddy damping to drive the pendulum chaotic.

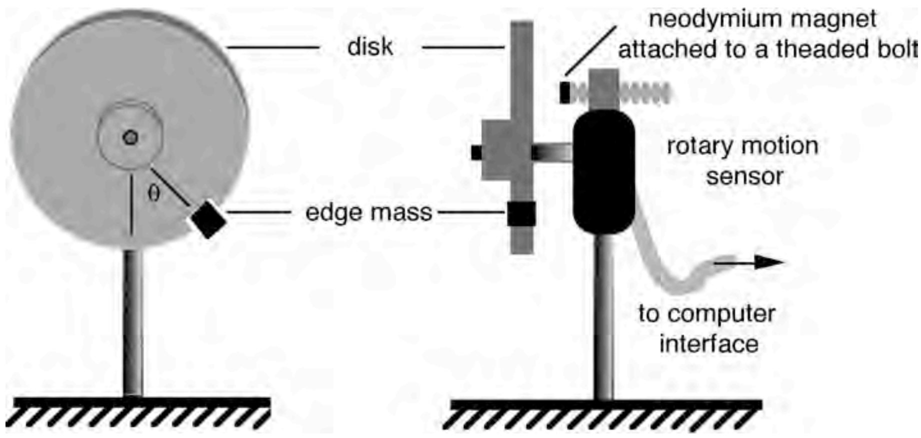


Fig. 1a **Fig. 1b**

Each segment of the unit is designed to fit within a 2-hour session which is typically used in *Workshop Physics* courses. Although it requires about 8 hours of student time to complete, the first 2 hours of activities do not require access to a laboratory and can be done independently.

Session One: An Introduction to Chaos

The introductory material includes a quote by Pierre LaPlace:

> *If an intellect were to know ... all the forces that animate nature and the conditions of all the objects that compose her, and were capable of subjecting these data to analysis, then this intellect would encompass in a single formula the motions of the largest bodies in the universe as well as those of the smallest atom; and the future as well as the past would be present before its eyes.*[5]

Students have just completed a study of simple harmonic motion in which the forces governing motion are well understood. So their first activity is to write a short essay about the viability of using Newton's laws to predict the state of the universe assuming that the forces of interaction between all the objects in the universe are known.

Students are then presented with the following quote by Henri Poincaré:

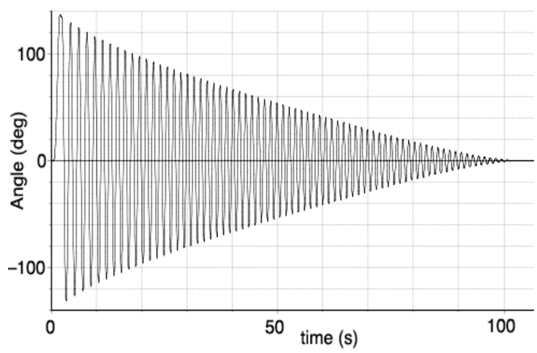
> *It may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible ...* [6]

Then they are asked to imagine whether or not the motion of the falling leaf in a closed box acting in the presence of known forces would be predictable. Students also view the one-hour NOVA videotape entitled *The Strange New Science of Chaos*[7] and answer basic questions about it, and they explore the sensitivity of a paper clip pendulum (with and without magnets present) to initial conditions.

Session Two: Large and Small Angle Pendulum Oscillations

In this session, students explore the deterministic and chaotic behavior of the physical pendulum system shown in Figs. 1a and 1b. They also keep track of the forces acting on the system and use these forces to develop either analytical or iterative models.

The session begins with qualitative predictions and observations of the motion of a disk mounted on a low friction rotary motion sensor shaft without and then with several edge masses. Then students collect data using the rotary motion sensor wired to computer data acquisition system. They create time series and phase plots of the rotational displacements and velocities of the pendulum (Figs. 2, 3).



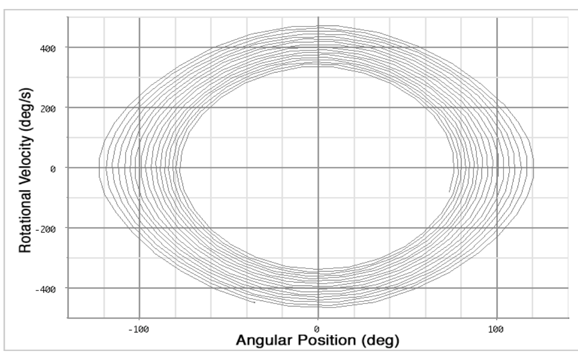


Fig. 2 **Fig. 3**

Session Two ends with students comparing the characteristics of large and small angle pendulum motions; first, through prediction and then by examining graphs of actual data.

Session Three: Using Iterations to Model the Motion

This session begins by preparing students to model their own large angle physical pendulum data by deriving the differential equation that describes the physical pendulum motion. The circles in the Fig. 4 depict a graph of typical large angle data.

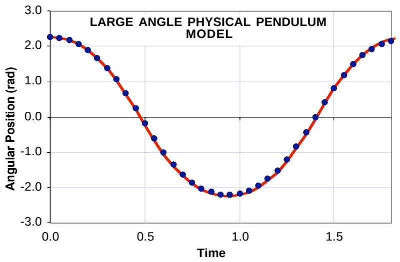


Fig. 4

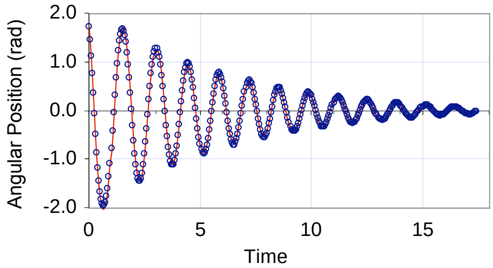


Fig. 5

Students are first asked to review the derivation of the differential equation that describes small angle simple pendulum motion. As an extension to their derivation in the previous unit on harmonic motion, we give students some hints that enable them to determine the differential equation that describes the motion of the physical pendulum oscillating with a large amplitude. They find that the rotational acceleration of the disk is given by

$$\alpha(t) = \frac{\tau^{net}}{I} = \frac{\tau^{grav}}{I} = -\left(\frac{mgR\sin(\theta(t))}{mR^2 + \frac{1}{2}MR^2}\right) \qquad \text{(Eq. 1)}$$

where I is the rotational inertia of a disk of mass M and radius R that has an edge mass of m.

Modeling Large Angle Motion: Because the differential equation for large angle motion cannot be easily solved analytically, we introduce students to a modified Euler method[8] -- an iterative numerical integration scheme for using the equation of motion to predict the rotational acceleration, velocity, and position of the pendulum as a function of time.[9] The line through the points in Fig. 4 shows a good agreement between the iterative spreadsheet model and experiment.

Adding Magnetic Damping Forces to the Physical Pendulum System: In the next part of the session, students position a damping magnet very close to the face of the aluminum disk to create significant eddy damping and a real time graph of angular position versus time for an initial angular position of about 135º. Then students were shown how to add the term $\tau^{damp} = -b\omega$ to Eq. (1) (the torque equation used in the iterative calculations). Adding this term and copying it down through the column in which it appears gives students instant results for their new model. By using the damping coefficient b as an adjustable parameter, students can obtain an excellent fit to their data like that shown in Fig. 5.

Session Four: The Chaotic Physical Pendulum

In this final session students modify their pendulum so that a string, springs and a driver motor are coupled to the disk and edge mass as depicted in Fig. 6.

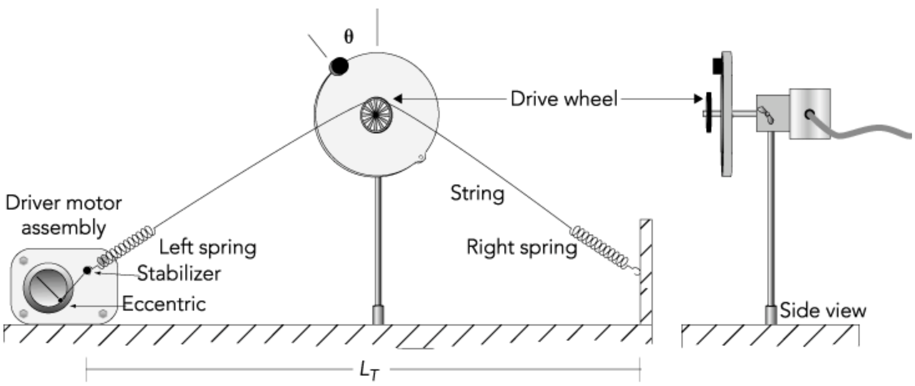


Fig. 6

Exploring the Natural Frequencies of the System: Students are asked to observe the natural oscillation frequencies of the apparatus when it is configured in different ways. This helps them understand why the system motion becomes chaotic when driven at certain frequencies.

Students start by observing and determining the frequency of oscillation of the disk without the edge mass added as it moves under the influence of torques caused by springs wrapped around the drive wheel (Fig. 6).

Next they configure the system as a pendulum by adding a small edge mass to it and measure the natural frequency of the pendulum without the springs. Then students re-attach the springs to the driver wheel of the pendulum and re-balance the system so the springs are stretched equally when the mass is perched straight up on the top of the disk at its unstable equilibrium point. Next, students measure the left and right equilibrium angles θ_L and θ_R with respect to a vertical axis as shown in Fig. 6. If the spring extensions are properly balanced, the magnitudes of these two angles are essentially the same.

Finally students measure the natural frequency of oscillation of the spring-pendulum system when the edge mass has fallen to the right of its highest possible position and again when it has fallen to the left.

Driving the System at Natural Frequencies: Students are asked to set the drive frequency of their electric motor to one of the natural frequencies they have measured, balance the springs so the edge mass points straight up, turn on the motor, and collect data for the angular displacement versus time. Students find that whenever the motor is near a natural frequency, the system settles rather quickly into a stable oscillation mode.

Driving the System Chaotic: In the next activity students set the drive frequencies so that they are different from any of the natural frequencies and see if they can achieve a situation in which there is an irregular pattern in the time series graph depicting the angular position versus time. A typical pattern is shown in Fig. 7 for the time series graph and the phase plot of the chaotic physical pendulum system.

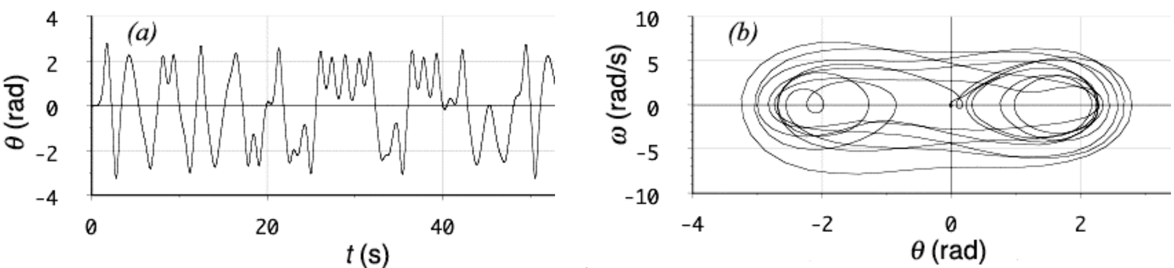


Fig. 7

Students find that their systems are so sensitive to the initial values of the angular position and rotational velocity that it is impossible for them to recreate the initial conditions accurately enough to repeat a pattern on either a time series graph or a phase plot for more than a few seconds.

Using an Iterative Model of the Chaotic Pendulum Motions: Students are led through a guided derivation of the four torques that act on the disk of the pendulum, including the gravitational torque on the edge mass, the eddy damping torque exerted on the aluminum disk by the magnet, the spring torques, and the torque exerted by the driver. We write the net torque as

$$\tau^{\text{net}} = \tau^{\text{grav}} + \tau^{\text{damping}} + \tau^{\text{spring}} + \tau^{\text{driver}} . \quad \text{(Eq. 5)}$$

The rotational acceleration is given by the net torque divided by the rotational inertia of the physical pendulum, or

$$\alpha = \frac{\tau^{\mathrm{net}}}{I} = \frac{\tau^{\mathrm{net}}}{\left(mR^2 + \frac{1}{2}MR^2\right)}. \quad \text{(Eq. 6)}$$

The notation used for the quantities needed in the torque equations are summarized in Table 1.

TABLE 1: Notation

Symbol	Name	Typical Value
m	edge mass	0.010 [kg]
R	disk radius	0.050 [m]
M	disk mass	0.143 [kg]
g	gravitational constant	9.8 $[\mathrm{m/s}]^2$
θ	angular displacement of the edge mass from upward vertical	variable [rad]
ω	Edge mass rotational velocity	variable [rad/s]
b	damping coefficient	$6.0\mathrm{x}10^{-5}$ [m-s/rad]
r	axle radius	0.025 [m]
A_{d}	driver amplitude	0.032 [m]
T_{d}	driver period	1.56 [s]
t	time	Variable [s]
ϕ	driver phase	0.0 [rad]

It can be shown that the torques are given by

$$\tau^{\mathrm{grav}} = mRg\sin\theta \quad \text{(Eq. 7)}$$

$$\tau^{\mathrm{damping}} = -b\omega \quad \text{(Eq. 8)}$$

$$\tau^{\mathrm{spring}} = -2kr^2\theta \quad \text{(Eq. 9)}$$

$$\tau^{\mathrm{driver}} = +krA_{\mathrm{d}}\cos[(2\pi / T_{\mathrm{d}})t + \phi]. \quad \text{(Eq. 10)}$$

In principle, students can now develop an iterative spreadsheet model describing the chaotic pendulum motion. Since the pendulum often obtains high rotational velocities as it whips back and forth, the Euler method students used for numerical integration will accumulate integration errors unless the time steps are extremely small. For this reason the author developed a second-order Runge Kutta integration[10] model for students to to use.

Revisiting of the Concept of Determinism. After finishing their lab work and modeling, students are asked to reconsider the viability of Laplacian determinism. In general, the student comments on determinism both before and after they work on the unit were disappointing. Instructors expected them to be surprised that the state of a chaotic system is unpredictable when the torques acting on it are known. Instead, students often commented that Laplacian determinism is not feasible because of quantum effects.

The questions about Laplacian determinism need to be worded more carefully. For example, students might be asked initially: ”Suppose that you could know the mass, shape, position and velocity of every object in the universe to eight significant figures, how the forces and torques between them depend on these four quantities, and that the universe is governed only by Newton’s laws of motion. How well could you predict the future?” The final question might be: ”What changes, if any, would you make to your answer to the first question? Why?” [11]

Conclusions

In spite of the overlap in the approach taken in the Chaos Unit with other *Workshop Physics* units that preceded it, the complexity of the pendulum system and the iterative spreadsheet modeling are still a stretch for many students. Nevertheless, we found that the Chaos Unit is both vexing and exciting to our students. Overall, we believe that our attempt to expose introductory physics students to profound aspects of contemporary physics is well worth the effort.

Adapting this unit to the laboratory portion of more traditional courses would require some modification. But the concepts that students need to understand the behavior of the chaotic pendulum are covered in the lecture portion of many introductory physics courses. Students would need to have prior experience in earlier laboratory sessions with computer data acquisition software and be exposed to the process of fitting their data to analytical functions using spreadsheets or other software tools. In this case, this unit could be adapted for use in the last three or four laboratory periods at the end of a mechanics laboratory sequence.

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SHOULD WE TEACH FOR CONCEPTUAL CHANGE OR PARADIGM CHANGE?

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A study of learners' alternative conceptions of time and space were conducted with 1068 first year university students from three Southern African universities. Since these concepts are fundamental to both physics and personal experiences of the world, a comparison of these alternative conceptions with those of physics were expected to clarify discrepancies between the ways learners and physicists perceive and explain the physical world. The results showed that two prominent features of the alternative conceptions were egocentrism and event-orientation. The consistency with which learners applied their alternative conceptions indicates the usage of an alternative paradigm to explain their experiences. This primordial paradigm differs significantly from the formal paradigm of physics. Consequently learners hold alternative conceptions and misconceptions that oppose the learning of physics. An effective approach to remedy learning difficulties in Physics may be to foster conceptual change through a paradigm change.

Introduction

Physicists strive to explain the physical environment (Cutnell & Johnson, 2004). Children also try to understand the physical world that they perceive and experience (Driver, 1997). Physics education research revealed that children's explanations of phenomena such as the rising sun or a falling stone differ from that of science (e.g. Driver *et al*., 1989; McDermott, 1993; Lemmer *et* *al*., 2003). The problem investigated in this study was why children experience difficulties in understanding physics.

Learners' alternative conceptions of a variety of scientific concepts have been reported, and teaching strategies to accomplish conceptual change were implemented (Scott *et al.,* 1992). Newtonian mechanics have been identified as particularly problematic due to resistive alternative conceptions in connection with force (Driver, 1997). Rowlands *et al*. (1999) argued that it seems more appropriate and useful to speak of an intuitive schema of force and motion instead of the concept of force. They reasoned that during instruction the concept of force is assimilated in a way that makes it compatible with the existing intuitive schema that has been built from experience of bodies in motion (Rowlands *et al*., 1999). Driver (1989) too discusses children's organization of ideas and relationships between them in terms of cognitive structures and frameworks

The hypothesis of this study was that learners make use of an alternative paradigm that causes a barrier to the understanding of concepts in formal physics. The aim of the study was to investigate the possibility of the existence of such a paradigm and whether it is consistent and logically structured. The word paradigm follows from literary science where its meaning is "an example or pattern" (Sykes, 1977). Kuhn (1973:viii) ported the term to scientific research and described it as "universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners".

The aim of the study was accomplished by means of an investigation of learners' alternative conceptions of time and space. These concepts are fundamental to both physics and everyday experiences, and played a crucial role in paradigm changes in the history of physics (Jammer, 1993, Morris, 1985). The following aspects were probed: the structure and properties of space and time, causality, referencing, sequential order and logic, motion, kinematic graphs and perceptions of the universe (Lemmer, 1999). More than a thousand (1068) first year students from three Southern African universities were involved in the study. The learners' perceptions were investigated by means of questionnaires, followed by recorded interviews with selected students who revealed interesting ideas in the questionnaires. The students' ideas about time and space were compared with those of classical mechanics as taught at secondary school. A survey of the historical development of these concepts in Physics (e.g. Jaki, 1992; Jammer, 1993; Morris, 1985) were used to identify different perceptions of time and space.

Results

Alternative perception of space and time were found in the learners' responses to the questionnaires. The alternative perception of space was called *topos* space after a word used by

Aristotle to indicate space as place (Lemmer, 1999; Lemmer *et al.,* 2003). *Topos* space is perceived as an assembly of finite spaces between, in, or around objects and has topological features. This differs from the Newtonian view of space as a uniform, homogeneous assembly of an infinite number of points and as described by Euclidean geometry. Similarly, the alternative perception of time (called *kairos* time) differs from the Newtonian perception of time as a uniform, arrowed time-line. In the *kairos* perception, time does not exist independently, but is constituted by events and thus not uniformly structured. The study revealed similarities in the properties of the alternative perceptions, i.e. of *kairos* time and *topos* space. Both *kairos* time and *topos* space are event-orientated, personal, qualitative and circumstantial. Space (place) and time are created by objects and events. Objects and events are described from a personal (egocentric) perspective in qualitative terms and in relation to the situation or circumstances. These features of the alternative perceptions are incompatible with Newtonian mechanics in which time and space exists independent of events. Impersonal situations (e.g. the motion of a body under action of a force) are described quantitatively, using precisely defined concepts and applying formal, causal laws within geometric space-time coordinates.

The results of the study indicate that properties of the alternative perceptions of *kairos* time and *topos* space also occur in concepts and aspects related to space and time, namely sequential order and logic, causality, scaling, referencing, graphical representation, motion and views of the universe (Lemmer, 1999; Lemmer *et al*., 2003). Prominent features of all these aspects are egocentrism and event-orientation. These features were also reported by Piaget and his co-workers (Piaget, 1969 and Piaget & Inhelder, 1956). Champagne *et al.* (1982) and Rowlands *et al.* (1999) too pointed out that learners' conceptions or schemata are event-orientated (situation-specific or context specific). For example, learners' alternative ideas depend on the form of motion presented. Learners do not recognise that the same physical laws apply to objects in free fall and to objects sliding down an inclined plane.

Deductions from results

The repetition in occurrence of features such as event-orientation and egocentrism in learners' alternative conceptions, together with the consistency found in their views of space, time and related concepts indicate that learners make use of an alternative paradigm to explain the physical world. Characteristics of learners' primordial paradigm are compared to those of formal physics in Table 1. Applications of these paradigms to aspects concerning force and motion are also compared.

Table 1: Comparison of learners' primordial paradigm with the formal paradigm of physics

	Primordial paradigm	Formal paradigm
Basis	Experiential-empirical	Experimental-empirical Theoretical
Criteria	Functional	Instrumental / technological
Features	Qualitative, relative, comparative Context-specific Personal / egocentric	Quantitative and metric Universal Impersonal, objective
Categories of motion	States: Stationary or moving Types: Driven or projected	Constant velocity (could be zero) and acceleration
Affector of motion	Propulsor (*causa motio*)	Force (accelerator)

Children interact from a very early stage with their surroundings to become practically acquainted with it. They observe and explain physical phenomena. Therefore their paradigm can be called experiential-empirical. In physics, well-established methods are used to conduct experiments to test hypotheses. A formal theoretical, mathematically described base of knowledge has been developed. While children's investigations are functional, physics uses instrumental or technological criteria.

From the investigation of 1068 learners' perceptions of space and time the following features of learners' paradigms were found in comparison to that of physics:

- Qualitative terms such as *long*, *fast*, *in a hurry* and *like lightning* are used to describe events. These terms are not uniquely determined, but relative to the event under consideration. For instance, the distance to town is long if you have to walk, but short by motorcar.

- When events are described, personal (egocentric) reference points are used. For example, the left front wheel of a motorcar is indicated as being from the observer's position, and not from the driver's. This is in agreement with findings of egocentrism reported by Driver (1997) and Piaget and Inhelder (1956).

- Learners' explanations of physical phenomena are event-orientated (situation-specific or context-specific). For example, where the definitions and laws of Newtonian mechanics are uniformly applied to all types of motion. The focus in the primordial paradigm is on the object that moves and the way it moves, i.e. on the event under consideration.

Rowlands *et al.* (1999:261) stated it in terms of the force concept: "Student reasoning tends to focus on the body in the context of the motion, rather than the motion in the context of forces acting on the body".

These features of the primordial paradigm differ completely from those of the formal paradigm of physics. In physics phenomena are described precisely and mathematically, using predefined quantities and units. The definitions, units and laws are universally valid, and applied in the same way in all situations. Observations are described in an impersonal, objective manner and in mathematical language (i.e. formally).

According to learners' everyday experience, an object either moves or remains stationary, while Physics distinguishes between accelerated and constant velocity motion. Learners do not understand how an object can keep on moving if there is no net force acting on it, because it is contradictory to their experience: A car needs an engine, a train a locomotive and a cyclist has to pedal a bicycle, whether the vehicle moves with constant velocity or not. To accelerate (move faster) one just has to pedal harder. In their experience objects *move*, instead of *accelerate*, due to a motive cause. Motion is propulsion and needs a propulsor. In uncontextualised physics tuition, learners associate the force concept with this *causa motio*. Force is perceived as the cause of *all* motion, instead of the cause of *accelerated* motion only. Hestenes and Halloun (1985) connect this misconception to Aristotles' idea of a motive power and the impetus theory of the 14th century.

A consequence of these alternative ideas about force and motion, can be expected to influence their understanding of Newton's laws. For instance,
while Newton's first law refers to

(a state of rest or motion with constant velocity)

the learners may understand it as

(a state of rest) or (a state of motion with constant velocity).

A miscomprehension of the concept of force follows, giving rise to a domino-effect of misunderstandings.

It is important to note that Kuhn (1973) stated that paradigms may be prior to, more binding, and more complete than any set of rules that could be unequivocally abstracted from them. In the formal paradigm of physics, the purpose of definitions of concepts is to provide a common, fixed (formal) agreement between scientists about the terminology. Definitions are not learning aids to produce insight in concepts. They should be the final step and not the first step in the teaching and learning of physics.

Conclusion

The repetition in occurrence of features (such as egocentrism and context-specific descriptions using qualitative, comparative terminology) in learners' alternative conceptions, together with the consistency found in their views of space, time and related concepts, indicate the usage of an alternative paradigm to explain the physical world. Alternative concepts and schematas are used in a sensible way in this alternative paradigm. The primordial paradigm differs fundamentally from the formal paradigm of physics and consequently influences their understanding of physics.

Children's science is thus not scientific knowledge in development, it is something dissimilar. According to Rowlands *et al.* (1999:262) an intuitive schema (such as the schema of force and motion) has to undergo a massive transformation in order to adapt to a new concept (such as the scientific concept of force). It is also true for the alternative paradigm that incorporates the alternative concepts and schematas. Instead of teaching for paradigm change through conceptual change, an approach to foster conceptual change through paradigm change is suggested, because concepts are given meaning in a paradigm. A paradigm change can only be accomplished by a change in the didactics of Physics teaching. This is discussed further in the paper on contextualisation as a didactical method for physics education.

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CONTEXTUALISATION AS A DIDACTICAL APPROACH FOR PHYSICS EDUCATION

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Three different didactical approaches to accomplish a transfer from learners' primordial paradigm to that of formal physics are discussed, namely formalisation, conceptualisation and contextualisation. Motivations are given for the introduction of a contextual approach which starts from the primordial paradigm held by learners and proceeds towards conceptualisation and formalisation. Different contexts should be used throughout the science curriculum to introduce learners to the formal paradigm of physics.

Introduction

In Physics repeatable empirical work, precise measurements and accurate calculations are used to investigate and describe the physical world. The paradigm of physics is formal, non-personal and generalised. Children, on the other hand, explain their experiences of their environments by using an informal paradigm which is egocentric and context-specific. In the science classroom learners have to be taught to understand and to use the formal paradigm of physics. Three different didactical approaches to accomplish this are discussed, namely formalisation, conceptualisation and contextualisation.

Formal approach

The formal approach is the conventional approach of physics teaching at school and tertiary education. Aspects of formalisation are the assignment of standard symbols and units, operational definitions and quantification of relationships. Physics learners are merely confronted with these formal aspects. In the first chapter of a typical first year university textbook (e.g. Cutnell & Johnson, 2004) the basic concepts such as time and space are defined in terms of their units. Then kinematics concepts are defined in succession through operational definitions, until Newton's laws are stated and applied. Finally the concepts of momentum, work and energy are introduced. Analytical and manipulative skills are developed by means of examples and problems stated in abstract terms without context, such as "An object with mass x kg is acted upon by a force of y N. Calculate its acceleration." This is a completely generalized and formalized approach.

Research in physics education produced increasing evidence that after instruction in such a formal physics course, many learners are unable to apply the physics formalism that they have studied to situations that they have not expressly memorized (McDermott & Shaffer, 1998; Driver, 1997). Misconceptions and alternative conceptions were identified in various fields of physics.

Conceptual approach

As a result of Physics Education Research (PER) an approach of conceptualisation has been emphasized in the recent past. Scott *et al.* (1992) reviewed different teaching strategies to promote conceptual change. They identified two main groupings, namely cognitive conflict and the resolution and building on learners' existing ideas. Learning is seen in terms of conceptual development or change rather than the piecemeal accretion of new information. In a conceptual approach, the emphasis is on comprehension of important physical concepts and scientific reasoning skills (Hewitt, 1993). A concept is introduced by an illustration from everyday experiences that motivates the introduction of the relevant physical concept (Griffith, 1992). Teaching strategies promote the active mental engagement of students in the process of learning physics, usually through guided experimentation or computer-aided instruction (Hake, 1998; Jackson *et al*., 2003). In mechanics, the apparatus used are mainly blocks, rolling balls or moving trolleys. In all cases the emphasis is on conceiving formal physics.

Conceptual approaches, especially those that use interactive-engagement methods, can increase effectiveness in mechanics courses well beyond that obtained in traditional practice (Hake, 1998). Although Redish *et al.* (1997:52) concluded that active-engagement microcomputer-based laboratory tutorials can be effective in helping students build conceptual understanding, they admitted that it do not provide a complete solution to the problem of building a robust and functional knowledge for many students. Concepts, especially those regarding force and motion, remained reluctant to change (Driver, 1997).

Contextual approach

In Lemmer *et al.* (2004) it was indicated that learners' alternative conceptions is a consequence of their primordial paradigm. Conceptual change should be fostered through a paradigm change. An approach to accomplish this is proposed, namely contextualisation.

The idea of teaching physics in terms of experiential, environmental, mental and historical context (e.g. White, 1989; Galili & Hazan, 2000) have been documented. Such lessons typically start with an everyday situation, natural phenomenon or reference to a historical event, to then proceed to formal teaching of physics and application of the knowledge gained in everyday situations.

However, this is a limited use (one aspect) of contextual physics, especially because each concept or topic is treated separately. Physics is still not introduced as a paradigm and perceived coherently.

The word *context* emanated from science literature in the sense that parts that precede or follow a passage fix its meaning (Sykes, 1977). Context refers to the ambient conditions. In a contextual approach the theory of physics should not only be developed, but also explained within the context of the paradigm of physics. The paradigm is discussed within the context of its own philosophical development. The following aspects form part of the context of physics:

(1) Philosophical context, which concerns aspects such as the world view of physics.
(2) Historical context of the development of physics.
(3) Technological context which includes the development of measuring techniques, empirical and technological equipment; as well as everyday applications.
(4) Mathematical context based on the mutual interaction between mathematics and physics.
(5) Relational context in which physics is related to other sciences such as chemistry and biology, as well as social sciences.
(6) Experiential context that refers to everyday experiences and learners' practical experiences of the world.
(7) Natural context, i.e. natural occurring phenomena or events, such as lunar eclipses.

All these contexts should be used throughout the science curriculum to introduce learners to the formal paradigm of physics. In contextualisation learners are made aware of differences between their paradigm and physics, and guided towards an understanding of the concepts, methods and structures of physics.

The aim of the contextual approach should be to establish an effective shift from the primordial paradigm held by learners to that of formal physics. This can be done effectively by starting from learners' practical experience and leading on to analytical thinking. In contextualisation attention is given to the basic questions of the paradigms of both the learners and physicists. In order to understand motion, the following series of questions should be discussed:

1. Why do objects move at all?
2. Why do objects move fast or slow?
3. Why do objects keep on moving after it is kicked, thrown, released, etc.?
4. Why do objects move faster or slower?

The first two questions deal with energy; and the third with momentum. The fourth question, that is the most complex, deals with forces. This question can only be addressed effectively after the answers to the first three are understood.

The series of questions given above is not only didactically and cognitively logic, but can also contribute to the prevention or elimination of misconceptions regarding force. Two persistent miscomprehensions are that force causes motion and force sustains 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. Instead of using force as the *causa motio* and the sustainer of motion, the learners are given other options which connects with their primordial ideas: 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.

After the energy concept has been established, the concept of work follows from the existential definition as the change in energy. A force (external agent) can do this work. In mechanics the change in kinetic energy (and thus velocity) can conceptually be connected with the concept of acceleration. For conceptual understanding, at least, a change in the order of introduction of the concepts from that of standard introductory physics curriculum (e.g. Cutnell & Johnson, 2004) is therefore proposed. Thereafter the concepts can be treated formally while constantly referring to the conceptual meanings.

From the discussion given above it can be deduced that physics could be learned more effectively if different manifestations of energy and transformations between them are introduced first. The question can be asked whether the concept of energy would not yield similar conceptual difficulties than the concept of force. Wesi (2003) reported a variety of learning difficulties and alternative conceptions associated with the energy concept. 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 easily 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 led to create a new scientifically correct schema (paradigm) which 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 the 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 afterwards approached in a step-by-step manner by means of examples and experiments. 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.

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. It is important always to proceed from everyday situations to idealised situations and then to formalization (generalization). For examples, resistive forces such as friction should be introduced conceptually before Newton's laws are discussed, because everyday experience include them. There are no examples from everyday experience that can be used to explain constant velocity motion as specified in Newton's first law (Robertson *et al.* 2004).

After explaining learners' experience that all moving objects eventually stop due to friction, idealized non-friction situations can be discussed and Newton's laws derived and applied formally. The historical experiment with marbles rolling on a J-shaped ramp can help with the abstraction to idealized situations (Robertson *et al.* 2004). This approach differs from the conventional didactical approach in physics which moves from the idealized situation (neglecting friction) to generalized (Newton's laws) to real situations (including friction). Such a contextual approach starts from the primordial paradigm, proceeds towards conceptualization and then to formalism.

Conclusions

Physics education research (e.g. Redish *et al*., 1997) showed that the formal approach to physics teaching is ineffective. Although more success is achieved with a conceptual approach, it remains inadequate in removing alternative conceptions and establishing a robust and functional knowledge framework. Contextualisation is expected to enhance effective learning of physics, because it works towards establishing a transfer from the learners' experiential paradigm to the formal paradigm of physics.

Contextualisation does not only imply changes in the order of presentation of information, but is a complete change in teaching approach. The formalised didactical approach begins and ends with formalism, with some conceptualisation and contextualisation where appropriate. The contextual approach starts from what the learners already know through personal experience and *refines* this knowledge (the Socratic way) gradually towards scientific knowledge. With this process understanding can be achieved, rather than acculturation as is the case with the formal approach.

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PHYSICS TO AFRICAN FOLK IN SOUTH AFRICA

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African students perform the poorest in physics compared to students of other races in South Africa. The observation is that this is due, at least in part, to language difficulties such as having to translate a physics concept from English as a language of instruction into a language understood for conceptualization (mother tongue). Such translations show that concepts are not always understood in the new language to mean what they mean in English. Lecturers should be aware of such difficulties and try to address them during physics lecturing to African students.

Introduction

Physics is taught to numerous groups of students of various backgrounds in tertiary institutions in South Africa. These groups study for various careers. Examples are: students majoring in physics, who need to understand basic physics concepts accurately and deeply so that they can build further physics knowledge on these concepts; medical students, who must understand the physics that is involved in the physiological human body functioning; and engineering students who must understand the physics principles and their applications in fields such as manufacturing. Some learners must understand physics in order to be able to pass it to others in the form of teaching, while some need to comprehend physics in order to interpret and explain phenomena to communities, such as heavenly bodies in astronomy. There are therefore various groups who must learn physics from different perspectives. Some perspectives are language and culture aligned, where students will understand physics in the light of their "cultural" beliefs, and in agreement with the way they understand the language of instruction. The language difficulty in particular is considered in this study as a contributing factor to difficulties in learning physics experienced by African learners.

Black African teachers and students study physics in institutions such as universities, colleges and technikons in South Africa, along with students of other races. They are taught mostly by lecturers who do not speak the same language or come from the same culture as they do. These lecturers usually use a language of instruction which is different from the vernacular of these African learners. Sometimes the language of instruction is also foreign to the lecturers themselves. Such are the circumstances under which African learners, who are subjects in this study, learn physics in South Africa.

In this study it is shown that the performance in physics of African students in South Africa is affected by language difficulties such as concept translation from the language of instruction into their mother tongue.

Literature

Graham (1995) stated that Physics is a "hard discipline" and warned that not everybody who is enrolled in it can pass. Dzama and Osborne (1999) report that beside physics being a difficult course, performance in physics is worse among African learners, where difficulties are caused by the absence of vocational incentives and African languages are not standardized (in terms of technical vocabulary).

Cobern (1991) reports that learners of different cultures interpret concepts taught through the filter of their own cultures. He thus encourages science education researchers to incorporate culture-sensitive aspects in curriculum developments. Ogunniyi (1988) however, indicates that some countries have succeeded in teaching physics in a traditional way that is nonetheless adapted to their culture.

Dlodlo (1999) reports that African learners do poorly in science at school because they fail to grasp scientific concepts which are explained in languages which are second or third languages to them, such as English. Language difficulties, he states, aggravate science conceptualization among these African learners. He therefore strongly suggests that African learners can only succeed in their studies in sciences such as physics if they are taught in languages which they understand, such as their own languages. He encourages physics- specific word coining and labeling of occurrences in the terms that would facilitate understanding of science in a particular language group, such as the Nguni language groups.

Strike and Posner (1985), Halloun and Hestenes (1986), Van Heuvelen (1991), Moji (1998), Grayson (2001) and others, warn that learners are not like empty vessels waiting to be filled with knowledge by lecturers. Rather, they have alternative conceptions which may not be scientific. The researchers thus warn that it is imperative that teachers be aware of these alternative conceptions of the learners. Teachers who know these alternative conceptions are armed with skills to confront them better than those who are not even aware that learners have alternative conceptions. They argue that when a teacher teaches, the content being taught is not directly absorbed into a learner's mind. Instead, the learner's existing knowledge is used to monitor the information being received from the teaching. If such information is recognized by comparing it with what is contained in the learner's background knowledge, it will be incorporated with ease by the student, while the information will be accommodated with difficulty if it does not agree with what is contained in the background knowledge. Champagne, Gunstone and Klopfer (1985) suggest a Demonstration-Observation-Explanation (D-O-E) approach which can be implemented to confront the current knowledge of learners if such knowledge is scientifically faulty.

Method

Sample

A study was done on two groups of students. The experimental group consisted of 116 African teachers of physics, both in-service and pre-service. Although they were from different schools, they were mainly from the Eastern Free State in South Africa. The control group consisted of 153 freshman Physics learners at the University of Natal, Pietermaritzburg. They were taught by the same professor. They were a mixture of races: 50 English speaking Whites, 32 English speaking Indians and 71 Africans of several different indigenous languages, in South Africa.

Study Instrument

An instrument consisting of two tasks was given to the subjects to respond to. Task 1 includes questions about a form of defense used by people in Lesotho during a war in which they rolled rocks down from the top of a mountain to the bottom, killing the enemy on their way down. At the end of the war, the rocks were rolled up the mountain again by men and boys in a form of a game. The questions asked were:

1. As rocks roll down, which quantities do they gain?
2. When a rolling rock collides with a stationary rock, which quantities does it impart to a stationary rock?
3. Some falling rocks can kill a man. For such a rock to kill a man, it must have a large amount of .....
4. Some small boys could not even move the rocks when they pushed. In terms of mechanics concepts, in what way are the boys different from men that pushed?
5. Man X and man Y rolled identical rocks along identical paths up the mountain. Man X finished his work ten minutes before man Y. In terms of mechanics concepts, how is man X different from man Y?

The correct answers are:

1. Speed, momentum, kinetic energy.
2. Momentum, kinetic energy.
3. Momentum, energy.
4. Force exerted.
5. Power expended.

Table 1 shows the results of the Experimental group on the question about the quantity the rock must have to kill a man; energy (kinetic) and momentum were expected together with their vernacular terms. 13% gave correct answers.

Table 1: To kill a man, a boulder must fall on him with much... (vernacular)

INS	N	PMA	SLJ	FMA	IMU	P	E	F	M	S	OTHE
		%	%	%	%	%	%	%	%	%	%
UNQ	20	10 (2)	10 (2)	15 (3)	-	10 (2)	15 (3)	20 (4)	10 (2)	5 (1)	5 (1)
B	4	50 (2)	-	25 (1)	25 (1)	-	-	-	-	-	-
BN	43	2 (1)	2 (1)	-	-	23 (10)	19 (8)	21 (9)	-	14 (6)	19 (8)
TAU	5	-	20 (1)	20 (1)	-	20 (1)	-	40 (2)	-	-	-
TS	6	-	-	17 (1)	17 (1)	-	-	50 (3)	17 (1)	-	-
T3	19	16 (3)	16 (3)	32 (6)	5 (1)	5 (1)	5 (1)	5 (1)	-	5 (1)	11 (2)
T2	19	5 (1)	-	16 (3)	5 (1)	32 (6)	-	32 (6)	-	5 (1)	5 (1)
TO %	116 100	9 8	7 6	15 13	4 3	20 17	12 10	25 21	3 2	9 8	12 10

INS :Institution
N :Number of subjects
PMA :Power/matla/amandla
SLJ :Speed/lebelo/jubane
FMA :Force/matla/amandla
IMU :Impact/matla/umfutho
P :Power
E :Energy
F :Force
S :Speed

B :Boitjhorisong
BN :Bonamelo
TAU :Taung
TS :Teachers
T3 :Tshiya College-3rd year
T2 :Tshiya College-2nd year
TO :Total
UNQ :University of the North-QwaQwa
M :Momentum
OTHE :Other responses

Table 2 shows the results for the quantity that is lacking from boys when men rolled rocks faster than them. Power expended was the expected answer. 30% answered correctly.

Table 2: Men rolled the boulders faster than boys, because ... (vernacular)

INS	N	PMA	EMA	FMA	FSM	P	E	F	M	OTHE
	%	%	%	%	%	%	%	%	%	%
UNQ	20	-	20 (4)	10 (2)	5 (1)	10 (2)	20 (4)	10 (2)	10 (2)	15 (3)
B	4	50 (2)	-	25 (1)	25 (1)	-	-	-	-	-
BN	43	5 (2)	-	-	5 (2)	35 (15)	19 (8)	14 (6)	5 (2)	19 (8)
TAU	5	-	40 (2)	-	-	40 (2)	-	-	-	20 (1)
TS	6	33 (2)	17 (1)	-	-	-	17 (1)	-	-	33 (2)
T3	19	26 (5)	26 (5)	16 (3)	11 (2)	-	5 (1)	-	-	16 (3)
T2	19	16 (3)	16 (3)	-	5 (1)	11 (2)	21 (4)	21 (4)	5 (1)	5 (1)
TO %	116 100	14 12	15 13	6 5	7 6	21 18	18 16	12 10	5 4	18 16

PMA :Power/matla/amandla
EMA :Energy/matla/amandla
FMA :force/matla/amandla
SM :Fit/strong/matla
P :Power
E :Energy
F :Force
M :Momentum

Table 3 shows the responses to the question about what the boys lacked when they could not even move some rocks. The expected answer was that they could not exert enough force. 16% answered correctly.

Table 3: Boys could not even move the boulders because ... (vernacular)

INS	N	NPM	NEM	NFM	WF	NP	NE	NF	W	OTHE
		%	%	%	%	%	%	%	%	%
UNQ	20	-	5 (1)	10 (2)	20 (4)	15 (3)	-	15 (3)	-	35 (7)

B	**4**	**25** **(1)**	**50** **(2)**	**-**	**25** **(1)**	**-**	**-**	**-**	**-**	**-**
BN	**43**	**2** **(1)**	**2** **(1)**	**-**	**5** **(2)**	**14** **(6)**	**19** **(8)**	**14** **(6)**	**21** **(9)**	**23** **(10)**
TAU	**5**	**-**	**-**	**60** **(3)**	**-**	**-**	**-**	**40** **(2)**	**-**	**-**
TS	**6**	**17** **(1)**	**17** **(1)**	**-**	**17** **(1)**	**-**	**17** **(1)**		**17** **(1)**	**17** **(1)**
T3	**19**	**26** **(5)**	**37** **(7)**	**5** **(1)**	**5** **(1)**	**-**	**5** **(1)**	**5** **(1)**	**-**	**18** **(3)**
T2	**19**	**18** **(3)**	**42** **(8)**	**-**	**5** **(1)**	**11** **(2)**	**26** **(5)**	**-**	**-**	**-**
TO **%**	**116** **100**	**11** **10**	**20** **17**	**6** **5**	**10** **9**	**11** **10**	**15** **13**	**12** **10**	**10** **9**	**21** **18**

NPM :No power/matla/amandla
NFM :No force/matla/amandla
NP :No power
W :Weak
NEM :No energy/matla/amandla
WF :Weak/not fit
NE :No energy
OTHE :Other responses

The survey shows that most subjects did not even give vernacular terms; those who did give vernacular terms had a problem to convert matla/amandla into English.

Table 4 shows how both the Experimental and Control groups compare in their answers to the same five questions of Task 1.

Table 4: Percentages of correct responses given by the Experimental group and by each sub-group in the Control group to Task 1

Question	**Experimental**	**Control Group**		
No.	**Group**	**Whites**	**Indians**	**Africans**
1	79	96	69	69
2	38	84	81	61
3	16	46	25	23
4	13	54	41	31
5	33	26	6	29

Task 2 is shown in Figure 1.

A ball is thrown up in the air, leaving the thrower’s hand, going almost vertically upwards; it reaches the highest position and then turns down to the ground. There are three positions of the ball marked:

1.When the stone has left the hand, on its way up.

2. At its highest position when it turns.

3.On its way down.

Draw arrows to indicate all forces acting on the ball at each position; the length of each arrow must show the size of the force. Each force must be properly labelled.

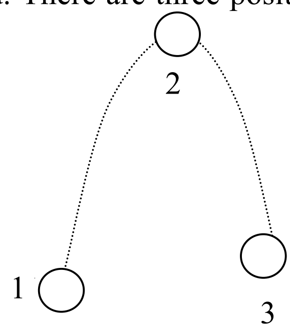

Fig. 1: Task 2

Table 5 shows how the Experimental group compares with the Control group in the answers to the same 3 questions of Task 2.

Table 5: Percentages of correct responses given by the Experimental group and by each sub-group in the Control group to Task 2

Position	Experimental	Control Group		
No.	Group	Whites	Indians	Africans
1	2	52	34	32
2	35	62	59	37
3	62	86	69	53

Discussion

While Physics is a “hard discipline” (Graham,1998), it seems even more difficult for African teachers and learners in the Experimental group, which is agreeing with what is indicated by Dzama and Osborne (1999). The results of this study show that African students are the poorest of the three races in performance, even though they were lectured by the same professor. These conceptual difficulties are apparently aggravated by language difficulties as shown in the five tables above. It is difficult to introduce conceptual change in learning for these African students to improve their physics, as is discussed by researchers like Grayson (2001), Halloun and Hesteness (1986) and Moji (1998), since there is language complexity intertwined with conceptual difficulty.

Meaningful learning occurs when a teacher who knows the alternative background knowledge of a learner guides the learner into appropriate conceptual change, as suggested by Grayson (2001), Moji (1998), Strike and Posner (1985) and Van Heuvelen (1991). African students in this study were apparently taught physics without considering misconceptions brought about by language in their background; such misconceptions must be addressed through language that the students understand; then adapting physics concepts to African cultural way of understanding as suggested by Cobern (1991) and Ogunniyi (1988) can follow.

While Dlodlo (1999) suggests a physics nomenclature in Nguni languages, Demonstration-Observation-Explanation (D-O-E) principle suggested by Chanpagne, Gunstone and Klopfer (1985) can be of general help not only to a particular group. It can also be important in any other language group among African folk by introducing physics specific nomenclature during the demonstrations of events, is necessary.

Conclusion

African learners and teachers both did poorly in the two tasks. If African teachers struggle in understanding physics concepts involved in the two tasks in this study they cannot effectively teach these concepts. Attention must be given to appropriate language labeling of the physics concepts by physics teachers from different language groups. Special attention should be given to African learners in physics in South Africa. In particular, they need teachers who are acquainted with their background understanding and their misconceptions. Furthermore, both teachers and learners need to be assisted in making correct connections between physics terms in English and vernacular words.

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SECONDARY SCHOOL EDUCATORS' APPROACH TO PRACTICAL WORK IN PHYSICS

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In South Africa a new approach called Outcomes Based Education (OBE) was introduced in 1995. A study was conducted to investigate problems experienced with practical work and skills needed for facilitation of practical work in physics at the FET-level by secondary school educators in the North-West province. The educators presented micro-teaching lessons on Ohm's law which were video-taped, analysed and discussed. The results of this study indicate limited understanding and interpretation of the outcomes and methodology of practical work in physics. The educators encounter difficulties to indicate characteristics of an OBE lesson, to prepare and to present an OBE lesson.

Introduction

Research in physics education indicates that physics practical work is heavily based on recipe-following with little attention paid to skills learning and teaching (Johnstone & Letton, 1990:11, Johnstone & Letton, 1991:83, Meester & Maskill, 1995:576). Recently new approaches to science laboratory work have been implemented (Hake, 1992).

Educators attempt to teach physics practical work but they do not properly know how to approach it with skill, speed and efficiency (Meester & Maskill, 1995:576). Olney (1997:1345) argues that approaches used by educators are cut-and-dried laboratory procedures which minimize learner involvement. Educators still prefer the authoritarian style of teaching, the emphasis being on the acquisition of factual knowledge and preparation for examinations. Hence, many fear the organisation of practical work and lack of skills required (Johnstone & Letton, 1991:83). Recently the most important role of practical work is seen as the teaching of practical skills

(Cilliers *et al*. 2000:28).

The empirical study was conducted with 46 educators attending an (Advanced Certificate in Education) ACE upgrading programme at the North-West University (Potchefstroom campus), South Africa. The educators were divided into six groups. One educator in each group presented a micro-lesson on Ohm's law while the rest of the group members role-played the learners. The micro-lessons were video-taped, analysed and discussed.

Results

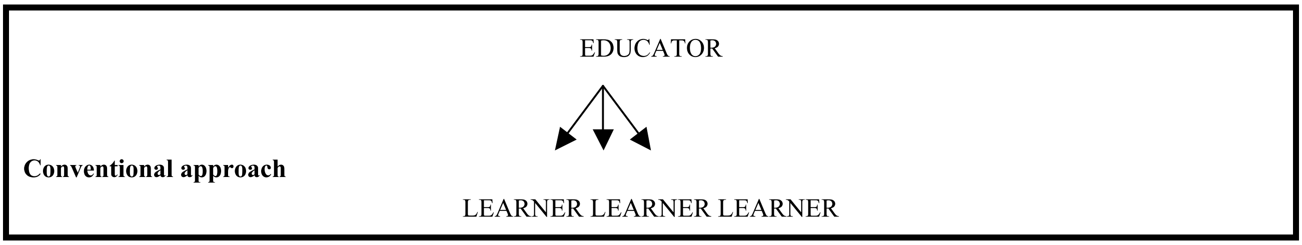
The video-tapes of the micro-lessons presented by educators on Ohm's law were analyzed. A comparison was made between the micro-lessons presented and the OBE requirements or expectations of the revised national curriculum statement (Department of Education: 2003). The results of the study are summarized in Table 1:

Table 1: A comparison between OBE requirements or expectations and the micro-lessons presented

Aspect of practical work	**OBE requirements or expectations**	**Micro-lessons presented**
Outcomes	Specified in context Problem-orientated Contextual	Formal and traditional Topical Every day life context Worksheet driven
Approach	Learner-centred Co-operative learning in groups Emphasis on outcomes	Educator-centred Group work Content based
Questions	Inquiry based and problem solving orientated Critical thinking Scientific reasoning Stimulate thinking, reasoning and understanding	Content based
Experimental procedure	Inquiry-based and problem solving orientated Hypothesizing Observing Gathering information Comprehension Synthesising Generalizing Communicating results and making conclusions	Content-based and recipe following Worksheet driven Instructed by the educator

	Discovery	
Role of educator	Facilitator Observe progress and problems experienced Intervene Guide Assess Identification and remedy of alternative conception	Instructor Lesson leader Passive Watch learners working Teacher demonstration Provider of knowledge Control the learners' work Writing of notes "Chalk and Talk" Educators conveyed alternative conceptions
Problem solving	Identification of problem Analysis of problem Design of procedures to reach solutions Application in scientific, technological, environmental and everyday contexts	Formal calculations Not contextual Educator-centred
Participation	Active learners Co-operative learning	Learners participate when instructed
Skills	Development of practical skills e.g. investigative skills, manipulative skills, observation, recording, interpretation, making deductions and analysing	Little attention paid to skills development Emphasis mainly on observation and recording skills

A comparison between the conventional approach, the approach used in the micro-lessons presented and the new outcomes based approach is indicated schematically in Figures 1, 2 and 3 below.



LEARNER LEARNER LEARNER

Figure 1: Schematic representation of the conventional approach

In the conventional approach (Figure 1) the educator is the source of knowledge. Learners are sited in rows and the educator dish out the knowledge. In general little or no interaction between learners occurs.

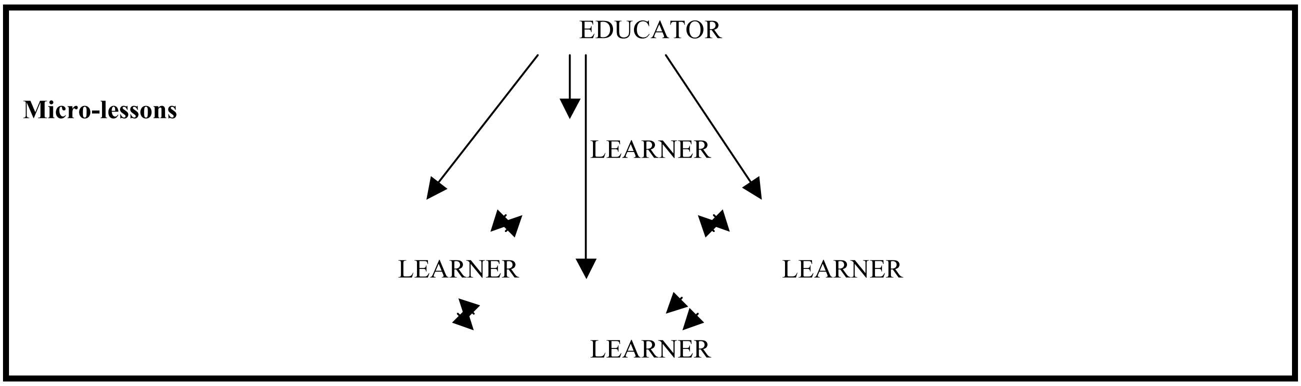


Figure 2: Schematic representation of the approach used in the micro-lessons

The approach used by the educators in the micro-lessons (Figure 2) is called an improved conventional approach by the researcher. The educator divides learners into groups but hardly ever use group work. Instead the educator goes back to the old conventional approach as a provider of knowledge and watch learners carrying out the instructions. Learners are sited in groups but there is limited interaction between them.

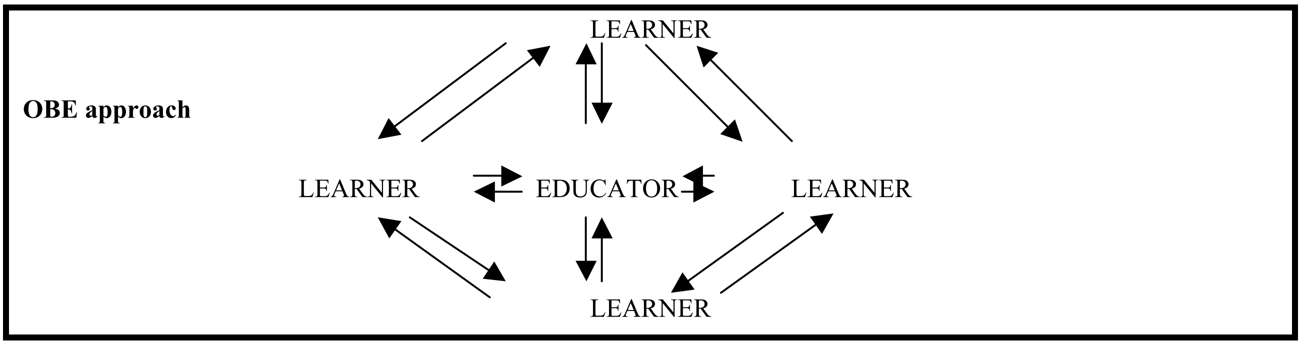


Figure 3: Schematic representation of an OBE approach

In the OBE approach (Figure 3) the educator facilitates learning and takes part by interacting with learners assisting those who experience problems and assessing the learning process. Learners interact with each other and engage in problem solving.

Discussion of the results

The study identified educators' difficulties and lack of skills in facilitating practical work in physics as summarised in Table 1.

The focus of outcomes-based teaching and learning according to Van Rensburg & Potloane (1998:27) is on what learners know and can do at the end of their learning experience. The development of an outcomes-based curriculum, therefore, will have as its starting point the intended results (outcomes) of the learning experience. These results refer to the knowledge, skills, attitudes and values which learners must acquire, and not merely the prescribed content. The researcher observed that the educators' approach to practical work did not fulfil these requirements. Instead of outcomes based approaches, the educators' approaches were educator-centred and content-based. The study indicates that the educators have limited understanding and interpretation of the outcomes of practical work. The outcomes indicated by the educators were mainly intended to learn the content; hence the outcomes stated by educators were formal, traditional and topical. The primary outcome given by the educators was to confirm Ohm's law; hence they use practical work primarily to confirm theory.

Conclusion

With consideration of the aim of this study the researcher observed that secondary school educators in the North-West province, South Africa do not fully understand their role in a practical activity, hence this impact on the way they facilitate a practical work in physics. This indicates that educators experience problems with and lack skills for facilitation of practical work in physics at the FET-level. The problem emanate from the finding that educators do not know how to implement the outcomes of a practical activity.

Viewed from the perspective of the camera the micro-lessons presented were mainly concerned with confirming theories, principles and laws in physics. In this case, the outcomes were mainly concerned with confirming Ohm's law. The activities did not incorporate real life situations to complement the theory and practical activities at hand. The development of inquiry and problem solving skills need specific attention during practical work. These inquiry skills include investigative skills, manipulative skills, making deductions and analysing. In an outcomes-based approach the context should be given by the educator and the learner guided to fit in the facts, hence the learner must develop a context as a frame of reference.

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HELPING STUDENTS DEVELOP AN UNDERSTANDING OF NET FORCE, NET TORQUE, AND THEIR RELATION TO RIGID-BODY MOTION: A RESEARCH-BASED TUTORIAL ON THE DYNAMICS OF RIGID BODIES

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Findings from an in-depth, systematic investigation were used to guide the development of a tutorial on rigid-body dynamics for use in introductory physics. The work described is part of the ongoing effort of the Physics Education Group at the University of Washington to improve student learning in physics through research and research-based curriculum development. Several factors contributed to the motivation for this investigation. These included the need that we perceived to identify and address conceptual and reasoning difficulties among engineering students in mechanics. As a first step, we observed students in sections of a sophomore-level engineering statics course at the University of Washington for which introductory physics is a prerequisite. From this experience and some preliminary studies that our group had conducted, it was clear that the students were encountering additional difficulties with basic concepts (*e.g.,* force) that do not appear in their study of particle dynamics. Several research tasks that illustrate the most prevalent and persistent of these difficulties are described briefly. We have found that explicit instruction on how to draw extended free-body diagrams that show forces at the location at which they are exerted to be necessary. The research also suggests that instruction must address incorrect ideas about the concept of force that spontaneously appear for many students in this context. The post-tests, while encouraging, underscore the challenge that physics instructors may encounter when teaching rotational dynamics.

Introduction

In this paper we describe the development of a tutorial to address student difficulties with the dynamics of rigid bodies found among students in a university-level introductory physics course required of science and engineering majors. This work is part of the ongoing effort of the University of Washington Physics Education Group (UWPEG) to improve student learning in physics through research and research-based curriculum development.

Recently the group has published a set of tutorials to supplement the lectures and textbook of a standard algebra- and calculus-based introductory physics sequence entitled *Tutorials in Introductory Physics* (McDermott *et al.,* 2001). A sufficient number of tutorials have been developed for an entire year of introductory physics. The tutorial on rigid-body dynamics is among three published tutorials on rotations.

The student populations that participated in this study were primarily comprised of university science and engineering majors. The students were in introductory calculus-based physics courses at the University of Washington and Purdue University where *Tutorials in Introductory Physics* had been implemented in the weekly small-group sections associated with each course. The tutorials are typically taught by teaching assistants (TAs) most of who are physics graduate students.

Description of Tutorials in Introductory Physics

The tutorial curriculum is organized by course content, namely, mechanics, electricity and magnetism and waves. The emphasis of the tutorials is in helping students develop conceptual understanding and reasoning skills. The instructional approach taken in many of these tutorials can be characterized by the sequence of steps: *elicit, confront, resolve, reflect, and generalize*. For a more extensive discussion of the tutorials see, for example, a set of papers by McDermott & Shaffer (1992). UWPEG continues to improve the existing set of tutorials as well as developing tutorials on special topics such as special relativity and quantum mechanics.

Each tutorial sequence includes a *pre-test,* a *tutorial worksheet,* and *tutorial homework.* The pre-test is a short, qualitative and sometimes quantitative written problem to probe student understanding of a topic of the tutorial and serves to elicit student difficulties by having students commit to a written response. The tutorial worksheets are a series of carefully structured written and experimental tasks that guide students through the reasoning necessary to develop a conceptual understanding of a topic. In tutorial, students typically confront common conceptual difficulties and are then asked to resolve contradictions between their own understanding and observations. Tutorial homework is meant to help students to extend, reflect upon, and generalize the concepts learned in the tutorial worksheets. In all cases, questions based on tutorial materials are covered on course examinations.

The tutorials are most effective if the TAs engage students by asking probing questions rather than lecturing. The preparation of the TAs to teach students in the tutorial sessions is an ongoing process. This requires of the TAs an in-depth understanding of both the physics content and the intellectual state of the student. McDermott explains (2001, p. 1134),

> Like most teachers, TAs tend to teach as they were taught. If they are to help undergraduates learn physics by guided inquiry, they need to experience this instructional approach and reflect upon the rationale.

At the University of Washington, the TAs participate in a weekly teaching seminar for as long as they are tutorial instructors.

Motivation for research and curriculum development

About the same time when the concept-based tutorials were first being developed and tested, we began to examine student performance in solving the types of mechanics problems assigned in the introductory calculus-based physics course. We hoped to develop tutorials that would help students learn how to solve such problems, especially those that require more than rote application of memorized algorithms. In 1996, the Physics Education Group was consulted by faculty in the College of Engineering about ways in which they could improve instruction in the sophomore engineering mechanics courses. We volunteered to advise them on the development of supplementary instructional materials for the statics and dynamics courses. We welcomed the opportunity to extend our investigation of problem solving to students in these courses, almost all of which had previously taken introductory physics.

As a first step in working with the engineering faculty, we observed students in sections of the statics course as they worked together in small groups on "hands-on" activities based on the course material. It soon became apparent that the students were struggling with concepts and principles that had been taught in the introductory physics course. For example, Ortiz, Heron, and Shaffer (2004) found among science and engineering students a persistence of an incorrect belief that *centre of mass* is the location around which the mass is evenly distributed, regardless of its mass distribution. During an individual interview with an engineering student who had just completed mechanics and asked to compare amounts of mass on either side of the centre of mass of a wooden baseball bat, the investigators found that (p. 9),

> Even after rejecting the idea that equal masses are required for balancing [of an extended object], this student persisted in believing that equal masses are found to either side of the centre of mass.

When the same task was administered as a written problem to a greater number of engineering students ($N = 80$), Ortiz, Heron, and Shaffer (2004) found that (p. 8),

> [A]fter eight weeks of instruction in engineering statics, only about 15% of the students correctly compared the masses.

The remaining engineering students (*i.e.,* ~ 85%) stated that the masses are equal.

From this experience and some preliminary studies that our group had conducted (Ambrose, Steinberg, Shaffer & McDermott, 1994), it was clear that the students were encountering additional difficulties with even more basic concepts (*e.g.,* force) that do not appear in their study of particle dynamics. We therefore decided to postpone the development of problem-solving tutorials for the calculus-based course until we could identify and address important conceptual issues that underlie success in problem solving. This decision marked the beginning of the investigation by Ortiz (2001, chap. 1 & 2).

This investigation draws on an extensive literature on student understanding of particle kinematics and dynamics as well as on methods to improve instruction on these topics. There is limited published research on student understanding of rotational dynamics at the university level. One such study conducted by Barowy & Lochhead (1981) identified student difficulties with the calculation of torque of an irregularly shaped object. We have obtained similar results that show that students are likely to leave a traditionally taught course with only a superficial understanding of torque, despite doing homework problems and experiencing relevant laboratory instruction (Ortiz, Heron, Shaffer & McDermott, 2001). For a description of what is typically taught on this topic, see, for example, Ortiz (2001, p. 498-502).

Student difficulties with net force and net torque

As the investigation progressed we found that many students had similar difficulties with the centre-of-mass motion of an extended object in the context of rotational motion (both pure rotational motion and combined translational and rotational motion) that do not appear in particle dynamics. In this section we describe the most serious and prevalent difficulties that the research has uncovered.

Research methods

One-hour individual demonstration interviews were conducted with ten student volunteers who had recently completed mechanics. The interviews were recorded on audiotape, transcribed, and analyzed. Students' answers and explanations were coded similarly by all of the raters. These interviews are patterned loosely after those done by Piaget (Inhelder & Piaget, 1958) in his investigations of the cognitive development of children. In these interviews, students are asked a series of questions and asked to respond to the questions while 'thinking aloud.' However, the interviews are open-ended, such that the interviewer is free to ask additional questions of the students to probe certain ideas more deeply.

In addition to interviews, written problems were administered to investigate student understanding. The written problems are short-answer conceptual problems. In essentially all of these problems, an explanation is asked for.

Problems administered

Two types of problems on the topic of two-dimensional rotational kinematics and dynamics were administered. One type of problem involves a ruler suspended from a fixed, frictionless pivot at its centre of mass. (The centre-of-mass acceleration and net force are zero, even when the ruler is being pushed down at one end.) The other type of problem is an acceleration comparison task involving several identical pucks on a level ice rink. Identical forces are exerted at a different point on each puck. Each puck has the same net force but different net torque about its centre of mass. Both problems included questions about net force, net torque, and centre-of-mass and angular acceleration.

Student difficulties with net force and net torque

We have found that many students have conceptual difficulties with the concept of force, which appear to stem from two characteristic and self-consistent apparent beliefs: (1) a force *decreases in effect* as the distance between the point of application of the force and the centre of mass increases and (2) the net force is the cause of *both* rotational motion and translational motion (of the centre of mass) as illustrated by a student in the study,

> Any force given to the block not used up in rotational acceleration will be given to translational acceleration.

When administered as a pre-test, about 60% of the students failed to recognize that the net force is zero when the ruler is pushed at one end so that it begins to rotate. These students explained that the net force *is the push.*

On the pucks problem, about 70% of the students ranked the accelerations as noted in (1) above on a pre-test. About 10% of the students gave a correct ranking. We found some students who reasoned on the basis of what may be interpreted as an argument based on energy. However, the analysis of data from these students suggests that the reasoning difficulty is more primitive than an incorrect attempt to solve the problem by using work and energy principles. Our interpretation is that students' previous Newtonian conception of force is maladapted, as described by beliefs (1) and (2) above, for cases in which a rigid body undergoes rotational motion.

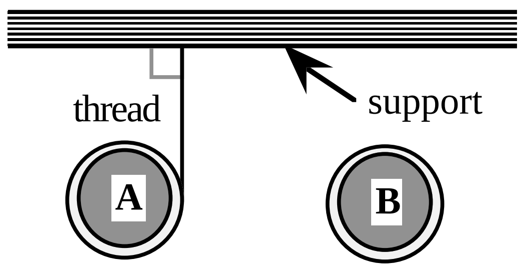
The development of a tutorial on the dynamics of rigid bodies

In the design of the tutorial on rigid-body dynamics, we chose to make use of the same or similar physical situations posed during the individual interview due to their effectiveness to elicit the difficulties we were attempting to address.

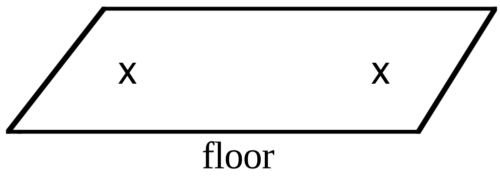
Description of the tutorial

The tutorial worksheets contain situations involving a stationary ruler on a pivot and a new task using two identical dropped spools. The instructional goals of these worksheets are to address aspects of student difficulties with the interpretation of the centre of mass and with distinguishing the effects of net force and net torque for extended objects. The worksheets make use of the extended free-body diagram in the two examples that are studied. We describe the dropped spool experiment in the following section.

In the last half of the tutorial, students are asked to consider the motion of two identical spools. Spool A is held directly below a crossbeam so that its string is vertical when attached at the beam. Spool B is held at the same distance from the ground. (Spool A's string is not attached to a crossbeam.)



Students draw extended free-body diagrams for each spool indicating all forces, type of interactions, and location at which each force can be taken as acting. The purpose of asking students to draw free-body diagrams here is to provide the framework from which students may begin to make connections with the mathematical formalism of rotational mechanics and observations.



Following the free-body diagrams for the spools, students are asked to indicate the direction of the net torque (taken about the centre of mass) on each spool. The intent of this question is to give students practical experience applying a right-hand rule to determine the direction of the vector cross product to determine torque. Before students make observations of the motion of the two spools, the tutorial asks for several predictions. The students are asked whether the two spools will hit the floor at the same time or at different times. The spools are released from rest from the same height. Students perform the experiment and observe that spool A hits the floor after spool B. Thus, those students who believe that the two spools will hit at the same time are confronted with their incorrect belief about force after watching the spools fall.

Near the end of the tutorial, a statement is given by a fictitious student regarding the motion of spool A. The explanation includes the incorrect belief that only forces that are exerted at the centre of mass affect the centre-of-mass acceleration. The students are asked to identify what is incorrect with the statement and discuss their answer with a tutorial instructor.

Effectiveness

When a slightly more difficult problem similar to the one described above was given as a post-test (after relevant instruction which included the rigid-body tutorial), fewer than 5% of the students made the error about force in the ruler problem. About 85% gave the correct answer with complete reasoning.

When a post-test containing a hexagonal puck with several forces exerted at different points was given (after relevant instruction and the rigid-body tutorial), only 5% of the students gave an incorrect answer consistent with the incorrect answer given on the pucks pre-test. About 60% gave the correct answer with complete reasoning on this post-test.

Conclusions

Many students leave the introductory physics course with the belief that the net force exerted on a body depends on the point of application of an individual force. Often they state that if a force is not exerted *at* the centre of mass, then part of the force is "used up" in the creation of rotational motion.

The research has informed the development of the rigid-body tutorial which has been assessed and proven to be effective. We are encouraged by these results, however, this investigation has shed light on even more student difficulties with rotational kinematics and torque (Ortiz, 2001).

The standard treatment of linear and rotational dynamics typically does not emphasize rigid bodies. The small amount of time devoted to this topic presumes that students can apply what they have learned in Newtonian mechanics for point particles to rigid bodies. This investigation suggests that this assumption can no longer be accepted.

For students who will continue on in engineering, it is important that instructors in the introductory physics course address these issues as effectively as possible. One way is to adopt the instructional pedagogy used in this tutorial which promotes an in-depth understanding of the concepts of net force and net torque of a rotating rigid body.

Acknowledgments

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ILLUSTRATING QUANTUM ENTANGLEMENT IN AN ELEMENTARY CONTEXT

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Here we propose a strategy to incorporate an elementary discussion of quantum entanglement into university courses in quantum mechanics. Basic aspects of quantum entanglement are illustrated in connection with a subject that is normally included in standard university courses and textbooks on quantum mechanics: the discussion of the kinematics and dynamics of spin one-half particles using two-component wave functions.

Introduction

Here we propose a strategy to incorporate an elementary discussion of quantum entanglement into university courses in quantum mechanics. Quantum entanglement has been the focus of intense research efforts in recent years. There is a general consensus that quantum entanglement constitutes one of, if not the most, representative aspect of quantum mechanics.

A state of a composite quantum system is called "entangled" if it cannot be represented as a mixture of factorizable pure states. Otherwise, the state is called separable. The entangled states cannot be prepared locally by acting on each subsystem individually (Galindo & Martín-Delgado, 2002 and Lo, Popescu & Spiller, 1998). Quantum entanglement can be regarded as a physical resource, which is associated with the peculiar non-classical correlations that are possible between separated quantum systems.

Entanglement lies at the basis of important quantum information processes (Williams & Clearwater, 1997, Williams, 1998, Bouwmeester, Ekert & Zeilinger, 1998 and Alber et al. 2001) such as quantum cryptographic key distribution (Ekert, 1991), quantum teleportation (Bennet et al.,1993), superdense coding (Bennet & Wiesner, 1993), and quantum computation (Ekert & Jozsa, 1996). The experimental implementation of these processes may lead to a deep revolution in both the communication and computational technologies.

Besides its possible practical applications, the study of quantum entanglement is of great importance on its own right. It constitutes an essential ingredient for a proper understanding of several fundamental aspects of physics, ranging from the quantum mechanical aspects of the second law of thermodynamics to the theory of quantum measurement and the emergence of a "classical world" from a quantum mechanical background.

In spite of being at the heart of quantum mechanics, a discussion of quantum entanglement is still lacking from courses in quantum mechanics. Most standard textbooks in quantum mechanics do not even have the word "entanglement" in their subject index. The aim of the present contribution is to illustrate some basic aspects of quantum entanglement in connection with a subject that is normally included in standard university courses and textbooks in quantum mechanics: the discussion of the kinematics and dynamics of spin one-half particles using two-component wave functions.

Quantum entanglement arises from the tensor product structure of the Hilbert space describing composite quantum systems. The Hilbert space associated with a particle with spin also exhibits this tensor product structure. Indeed, the study of spin usually constitutes the first instance of a tensor product Hilbert space that students encounter during the study of quantum mechanics.

Consequently, the chapter on the two-component wave functions formalism for spin one-half particles is an appropriate place to incorporate an elementary discussion of quantum entanglement. Following these lines we are going to address the following aspects of entanglement:

- The difference between separable and entangled states.
- A quantitative measure of entanglement.
- An illustration of the relevance of entanglement for quantum mechanical measurement processes.

Spin One-Half, Entanglement, and the Standard Quantum Mechanics Course

We now consider in some detail how these topics fit into a standard course in quantum mechanics. First of all, it must be stressed that all the technical ingredients (both mathematical and physical) needed for a meaningful discussion of the above list of items are already included in standard quantum mechanical courses.

The present proposal does not imply the incorporation of new, time consuming technical developments. Rather, what we propose is to use ingredients that are already being taught, in order to also teach a fundamental and extremely important concept of quantum physics: entanglement. The two-component wave function formalism associated with spin one-half particles is a standard subject in quantum mechanics courses. This formalism describes a tensor-product Hilbert space obtained as the tensor product of two Hilbert spaces: the two-dimensional Hilbert space associated with spin and the infinite-dimensional Hilbert space associated with the translational degrees of freedom. The basic features of this tensor-product space are usually taught (even though its tensor-product nature is not always explicitly stated). What we propose here is to use this important instance of a tensor product Hilbert space also to explain the concept of quantum entanglement.

In this regard, the basic difference between product states and entangled states can be illustrated with some simple examples of two-component wave functions, almost without the need of mathematical computations. On the other hand, in order to discuss a quantitative measure of entanglement one has to compute (via the evaluation of rather simple integrals involving the two components of the wave function) the marginal density matrix associated with the spin's degrees of freedom. The manipulation of this two by two Hermitian matrix implies mathematical techniques which are certainly within the reach of students of university courses of quantum mechanics.

To illustrate time dependent situations one can use special two-component states based on Gaussian wave packets. Again, the study of Gaussian wave packets is normally included in standard courses of quantum mechanics. The incorporation of the Gaussian packets into a discussion of entanglement in two-component wave functions constitutes indeed an interesting opportunity for the students to apply these wave packets. Finally, all these ingredients can be put together in a discussion of the time evolution of entanglement in the Stern-Gerlach experiment. The Stern-Gerlach experiment is one of the most important experiments in the history of physics. Due to its conceptual relevance, it plays a fundamental role in the teaching of quantum mechanics. Within our present approach, the Stern-Gerlach experiment also provides a valuable opportunity for discussing the role of entanglement in quantum measurement processes.

Spin One-Half particles and Entanglement

Two-Component Wave Function

Let us consider a pure state of a spin one-half particle described by the state vector:

$$|\Psi\rangle = \int \left[f_+(\vec{r})|\vec{r}\rangle|+\rangle + f_-(\vec{r})|\vec{r}\rangle|-\rangle \right]$$

where $f_+(\vec{r})$ and $f_-(\vec{r})$ are complex-valued functions of the position vector $\vec{r}$, and

$$|+\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \qquad |-\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

are the eigenstates of the z-spin component operator S_z with eigenvalues $\hbar/2$ and $-\hbar/2$ respectively.

Even if the complete state of the particle is pure, the spin degrees of freedom and the translational degrees of freedom are, when considered in their own, described in general by mixed states. The density matrix associated with this pure state, can be written as follows:

$$\hat{\rho} = |\Psi\rangle\langle\Psi|$$

The states characterizing "individually" the spin and the position degrees of freedom are given, respectively, by the partial traces of $\hat{\rho}$ with respect to the spatial and spin variables.

We shall think now of $|\Psi\rangle$ as describing a "composite" system including translational plus spin degrees of freedom. We proceed now to evaluate the partial trace of $\hat{\rho}$ over the position coordinates, which reads,

$$\hat{\rho}^{(S)} = Tr_{\vec{r}}(\hat{\rho})$$

Using $Tr\left[\rho^{(S)}\right] = \hat{\rho}_{++}^{(S)} + \hat{\rho}_{--}^{(S)} = 1$ and $\hat{\rho}_{+-}^{(S)} = \left[\hat{\rho}_{-+}^{(S)}\right]^*$ the marginal density matrix describing the spin variables can then be written as

$$\hat{\rho}^{(S)} = \hat{\rho}_{++}^{(S)}|+\rangle\langle+| + \hat{\rho}_{+-}^{(S)}|+\rangle\langle-| + \left[\hat{\rho}_{+-}^{(S)}\right]^*|-\rangle\langle+| + \left(1 - \hat{\rho}_{++}^{(S)}\right)|-\rangle\langle-|$$

Evaluating Entanglement

The entanglement of the pure state $|\Psi\rangle$ is given by de von Neumann entropy of the marginal density matrix describing one of our two subsystems, say, that describing "spin"

$$E\left[|\Psi\rangle\right] = -Tr\left[\hat{\rho}^{(S)} \ln\left(\hat{\rho}^{(S)}\right)\right]$$

Let $\{|0\rangle, |1\rangle\}$ and $\{\lambda_0, \lambda_1\}$ be the eigenvectors and eigenvalues of $\hat{\rho}^{(S)}$ respectively.

With these quantities we can express $|\Psi\rangle$ according to its Schmidt decomposition (Ekert & Knight, 1995) in the following fashion

$$|\Psi\rangle = \int d^3r \left(\sqrt{\lambda_0} f_0(\vec{r})|\vec{r}\rangle|0\rangle + \sqrt{\lambda_1} f_1(\vec{r})|\vec{r}\rangle|1\rangle\right)$$

The functions $f_0(\vec{r})$ and $f_1(\vec{r})$ are, in general, different from the above-mentioned $f_+(\vec{r})$ and $f_-(\vec{r})$. As $\hat{\rho}$ is a Hermitian operator, we can express the entanglement as follows:

$$E\left[|\Psi\rangle\right] = -\sum_{i=0}^{1} \lambda_i \ln \lambda_i$$

According to this expression we have to calculate the eigenvalues of $\hat{\rho}^{(S)}$ in order to evaluate the entanglement of our system.

$$\det\left(\hat{\rho}^{(S)} - \lambda I\right) = \det\begin{pmatrix} \hat{\rho}_{++}^{(S)} - \lambda & \hat{\rho}_{+-}^{(S)} \\ \hat{\rho}_{-+}^{(S)} & \hat{\rho}_{--}^{(S)} - \lambda \end{pmatrix} = 0$$

Thus,

$$\lambda_{1,2} = \frac{1}{2} \pm \frac{1}{2}\sqrt{1 - 4\det\left(\hat{\rho}^{(S)}\right)}$$

One Dimensional Gaussian Wave Packets

We are going to consider states of a spin one-half particle (moving in one dimension) described by two Gaussian wave packets,

$$f_{\pm}(x) = \frac{1}{\sqrt[4]{4\pi}}\sqrt{a_{\pm}}\,\exp\left[ik_{\pm}\left(x - x_{\pm}\right) - a_{\pm}{}^{2}\left(x - x_{\pm}\right)^{2}/2\right]$$

where $a_{\pm} > 0$ and $k_{\pm}$ are real constants. The quantities $a_{\pm}$ are related to the widths of the wave packets through the expression $a_{\pm} = 1/\sigma_{\pm}$. The probability densities associated with the wave packets $f_{\pm}$, $|f_{-}(x)|^{2}$ and $|f_{+}(x)|^{2}$ are centered, respectively, at $x = x_{-}$ and $x = x_{+}$.

In order to build up $\hat{\rho}^{(S)}$ we have to evaluate the integrals

$$\hat{\rho}^{(S)}_{LK} = \int_{-\infty}^{\infty} dx\, f_{L}(x) f_{K}^{*}(x)$$

where $L = +\,,\,-$ and $K = +\,,\,-$.

Once we have $\hat{\rho}^{(S)}$ we are able to obtain its eigenvalues and finally, evaluate $E\left[|\Psi\rangle\right]$.

Time dependent Wave Functions and Entanglement

The Free Particle

We start our considerations by setting

$$f_{\pm}(x) = \sqrt{\frac{a_{\pm}}{2\sqrt{\pi}\left[1 + i\left(\hbar a_{\pm}^{2} t/m\right)\right]}}\exp\left[ik_{\pm}\left[\left(x - x_{\pm}\right) - \frac{\hbar k_{\pm} t}{2m}\right] - a_{\pm}{}^{2}\left(x - x_{\pm}\right)^{2}/2\right]\exp\left[-1 - i\left(\hbar a_{\pm}^{2} t/m\right)\right]$$

Following the above mentioned procedure, we obtain $\lambda_{1,2}$.

Of course, once we have the eigenvalues we can straightforwardly evaluate $E\left[|\Psi\rangle\right]$.

Entanglement in the Stern-Gerlach experiment

In the Stern-Gerlach experiment, a beam of particles moving parallel to the x-axis are passed through a non uniform magnetic field B contained in the plane perpendicular to the axis. This field has a constant component of intensity B_{0} and a gradient of intensity β.

The Schrödinger equation describing this system is $H|\Psi\rangle = i\hbar\frac{\partial}{\partial t}|\Psi\rangle$ with the Hamiltonian

$H = \frac{\vec{p}^{\,2}}{2m} + \frac{g\mu_B}{\hbar}\vec{S}.\vec{B}(\vec{r})$ where μ_B is the Bohr magneton, and g is the gyromagnetic ratio.

Solving the coupled Schrödinger equations for each spinor component (Platt, 1992 and Vandegrift, 2000) we can obtain wave packet solutions for the Stern-Gerlach experiment (Roston , Plastino, Casas & Plastino, 2004) of the form

$$\Psi_\pm(z,t) = \sqrt{\frac{\left(2\sqrt{\pi}\right)^{-1} a_\pm}{1+i\hbar a_\pm^2 t/m}}\exp\left[\frac{-\left[z-z_\pm(t)\right]^2 a_\pm^2/2 + ik_\pm\left[(z-z_\pm(t)) - \hbar k_\pm t/2m\right]}{1+i\hbar a_\pm^2 t/m}\right]\exp\left[iT_\pm(z,t)\right]$$

$$T_\pm(z,t) = \frac{m}{\hbar}\left(v_0 z + a_c zt - \frac{1}{2}a_c v_0 t^2 - \frac{1}{6}a_c{}^2 t^3 - \frac{1}{2}v_0{}^2 t + c_0\right) \mp \frac{g\mu_B B_0 t}{2\hbar}$$

where c_0 is a real constant.

The pertinent correspondent eigenvalues are

$$\lambda_{1,2} = \frac{1}{2} \pm \frac{1}{2}\exp\left(\frac{g\mu_B\beta}{2m}\right)^2 t^2\left[\frac{-4m^2/\hbar^2 - 5t^2a^4 - a^8t^4\hbar^2/m^2}{4a^2\left(1+a^4t^2\hbar^2/m^2\right)}\right].$$

Discussion

Fig. 1 represents the entanglement function $E|\Psi\rangle$ corresponding to the one dimensional Gaussian wave packets. In this case the entanglement function is time invariant. This Figure shows $E|\Psi\rangle$ in terms of x for three cases:

(a) $a_+ = a_- = a$ and $k_+ = k_-$, x turns out to be $x = -\left(x_+ - x_-\right)^2 a^2/2$

(b) $a_+ = a_- = a$ and $x_+ = x_-$, x turns out to be $x = -\left(k_+ - k_-\right)^2/2a^2$

(c) $x_+ = x_-$ and $k_+ = k_-$, x turns out to be $x = \ln\left(a_+/a_-\right)$

The curves for case (a) and (b) coincide.

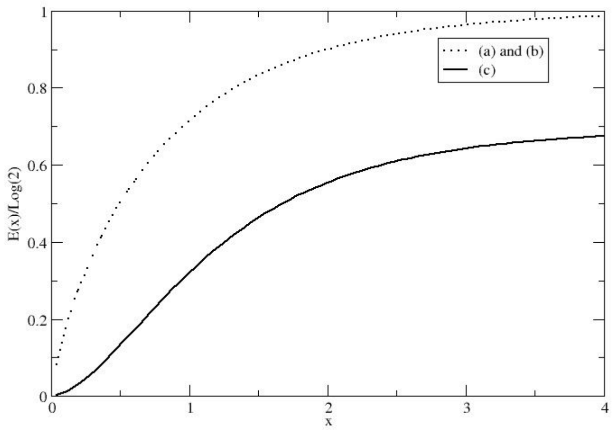

Figure 1: Entanglement function for One Dimensional Gaussian Wave Packets

For the Stern-Gerlach experiment the entanglement becomes dependent of time as we can see from Fig. 2. This figure shows the time dependence of $E|\Psi\rangle$ for different values of $g\mu_B\beta/2m$ being (a) 0.1, (b) 0.5, (c) 1 and (d) 2.

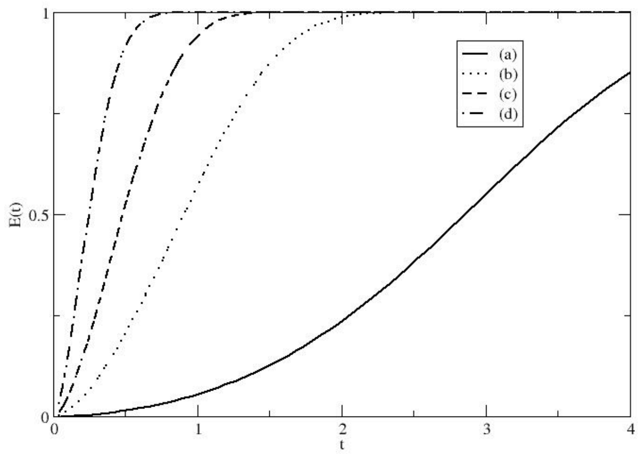

Figure 2: Entanglement in the Stern-Gerlach Experiment

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THE GLITTER PATH: AN EVERYDAY LIFE PHENOMENON RELATING PHYSICS TO OTHER DISCIPLINES

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The sun's reflection becomes a shining sword on the water
stretching from shore to him.
Italo Calvino

The many faces of the so-called glitter path are presented to draw attention to an optical phenomenon which is not only interesting from a physical point of view but is also important in other contexts. It is shown as well, that this phenomenon may occur in many situations totally different from the original wet ambiance.

Introduction

The phenomenon of the setting sun's reflections painting an elongated shiny path of light on the surface of wavy water is well known. Although physicists will regard it without hesitation as a physical phenomenon, non physicists including our students who experience this glitter path will be more affected by its non physical aspects. Like other natural or everyday life phenomena the glitter path may be regarded from different perspectives.

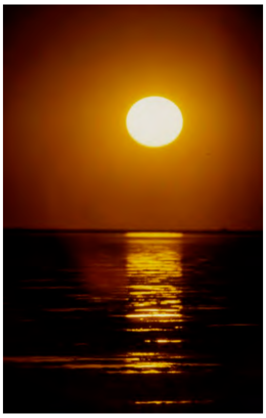

Fig. 1: Glitter path at the setting sun

First of all it is a popular motif of postcards, where it may be found not only associated with the setting sun but also as light streaks on rivers, channels and wet streets reflecting street lighting and other light sources. Moreover, the light path is a favoured motif in art throughout the centuries. Some painters as e.g. William Turner and Edward Munch spent much time on it exploiting its imagery and its esthetical and affective dimensions.

In literature the glitter path has been described many times. Like the painters, the poets were not only interested in the natural phenomenon itself but tried to express or intensify emotions and aesthetical sensations, or used it as a metaphor to illustrate their philosophical reasoning.
The light path is considered as an example of an everyday life phenomenon suitable for illustrating important aspects of learning physics within a non-physical context. We expect that we may take advantage of the motivation originating from the non physical aspects of the phenomenon to get the students interested in the physics behind it. Furthermore, the students should learn that the physical aspect of everyday life is just one aspect among others. We first give a description of the physical background of the phenomenon and then sketch how the various forms occurring in different situations may be modelled mathematically and reproduced by a simple computer simulation.

Fig. 2: The typical shape of a glitter path when the sun is not too low.

It can be expected that the physical understanding may help students to detect glitter paths in totally different situations: Light beads on tiled floors, on smooth metal surfaces, on CDs. They all have wavy surfaces in the form of ripples and scratches, and their behaviour may be observed and recognised as being based upon the same physical principles.

Finally, it is shown that by looking through transparent plates similar light patterns can be detected, which are no longer due to reflection but to refraction at ripples and scratches.

The glitter path in non-physical contexts

Light paths and light bands can be found in many paintings. First of all, they are powerful manifestations of light sources like the sun or street lamps in the surroundings, in that they multiply and modify the light impression by interacting with non luminous objects. Regarding the painting it becomes obvious that the painters often needed more paint for the light path than for the light source from which it originates. Conversely, the reflections are an important means to show the detailed structure of the water surface, which - due to the transparency of water - cannot be seen directly. Beyond the possibility to represent the material world, the painters exploit the many correspondences and allusions between mental reflections of the mind and light reflections of the water surface.

Fig. 3: William Turner: The Fighting Temeraire 1839. London: National Gallery

Fig. 4: Vincent van Gogh: Starry night over the Rhone. Paris: Musée d’Orsay 1888

After analysing in detail the techniques William Turner uses to represent reflections on water surfaces, John Ruskin (1900) states:

> There is more… than any philosophy of reflection, or any peculiarity of means can account for or accomplish; there is a might and wonder about which will not admit of our whys and hows.

The glitter path has been described across the ages in many different situations by poets and writers, not only as an appealing phenomenon accompanying the sun set and as a projection of affections but also as a philosophical metaphor.

The protagonist in a story of Italo Calvino, Mr. Palomar, notes during his evening swim:

> When the Sun begins to go down, its reflection takes form on the sea: from the horizon all the way to the shore a dazzling patch extends composed of countless swaying glints; the sun's reflection becomes a shining sword in the water stretching from shore to him. He swims in that sword . . (Calvino 1995).

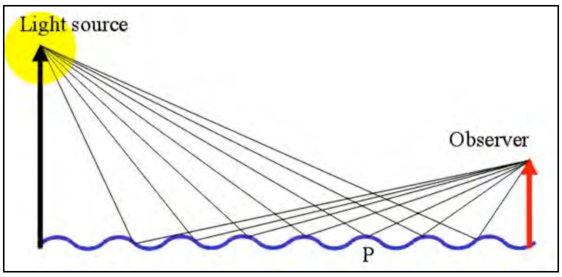

Fig. 5: A wavy water surface contains many inclinations from which light originating from the source is reflected to the observer.

But what about the other swimmers at that time of the day, are they swimming in the same or each in their own sword? Where is the sword situated, everywhere or nowhere? “The sword is imposed equally on the eye of each swimmer; there is no avoiding it. ‘Is what we have in common precisely what is given to each of us as something exclusively his?’” Palomar reflects on the light reflections: “Perhaps it was not the birth of the eye that caused the birth of the sword, but vice versa, because the sword had to have an eye to observe it at its climax.” Finally “he has become convinced that the sword will exist even without him" (Calvino 1985).

Reading this text students may be interested to find out if the peculiarities, especially that the sword is always directed to the observer, may have a sound physical explanation.

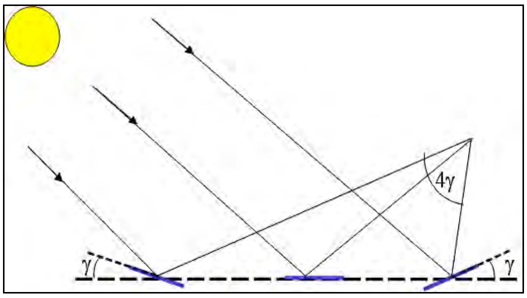

Fig. 6: The more the waves are inclined, the larger the area of possible reflections may be.

Physical reflections on the light reflections

The glitter path is due to the reflection of some light source. Normally, this is recognised even by younger students. But how is the light forced in such longish shapes?

Starting from a flat surface only one reflection (at the point P in Fig. 5) hits the eyes of the observer. In order to receive light from other points of a plane there must be a suitable inclination of the waves reflecting the light. The more distant those points are from point P the larger must be the inclination. Therefore, given a distribution of slopes below a maximal value, reflected light can only be seen within a certain area around P the extent of which increases with the maximum height of the waves. Apparently, the frequency with which the slopes change suffices to give the impression of a nearly continuous lit area to our eyes, apart from some fluctuations of the intensity – the glittering. Thus, the glitter path is the ensemble of countless reflections of some light source at suitably tilted water waves.

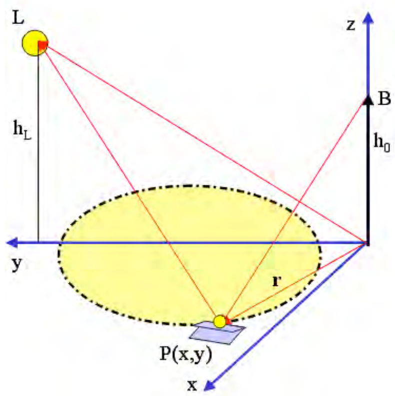

Fig. 7: The boundary of the area lit up by reflected light depends on the heights of the light source L and the observer B and on the maximal slope of the waves

The extension of the glitter path can be estimated by simple arguments. As can be concluded from Fig. 6 the angle of this extension is just 4 times the tilt angle of the waves.
The calculation of the boundary leads to a curve of 6^{th} order and shall not be given here. Instead, we sketch the algorithm of a computer simulation for the shape of the glitter path. Given are the maximum slope of the waves and the heights of the light source and the observer. Representing the water surface by a blue coloured plane for each point (pixel) between light source and observer the slope necessary to reflect light from this point into the eyes of the observer is calculated. If the calculated slope is less than the maximum slope the point is coloured yellow, if not it is left unchanged.

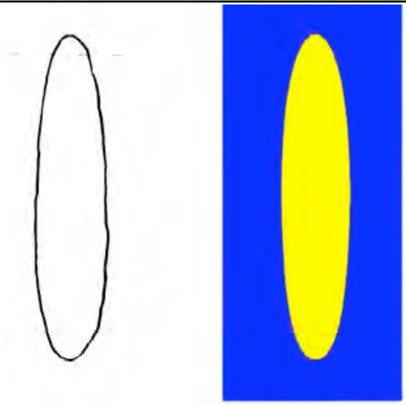

Fig. 8: Left: Plotted boundary. Right: Calculation of the reflecting area of the same situation.

As the observed shape of the glitter path is affected by the perspective, especially in the case of the low sun, the corresponding change was included in the program. For instance, when the sun is low the light band seems to have the same width all along the path. However, as we know from the rails of a railway track, which converge towards the horizon, this means, that in reality the light path broadens towards the sun. When we see a glitter path in the form of a band of light of equal width (fig. 1) in reality the path is a triangle with the broad side at the horizon.

A very simple experimental approach to the glitter path is sketched in Fig. 7. A tilted mirror the slope of which can be adjusted to different values and which has a pen on its bottom side can be moved along the boundary, thus plotting it on a sheet of paper. This can be done by looking through a small hole at B and controlling that the image of the light bulb L can always be seen in the mirror. The area surrounded by this curve can then be compared with the bright area calculated by means of the computer program (See Fig. 8).

The glitter path is not restricted to wavy water surfaces. Looking, for example, at a plate of glass lubricated by some grease, we can observe light paths of different shapes just by looking on it from a suitable angle.

Fig. 9: Light swords pointing into the wetted street.

The glitter path is a specular reflection phenomenon. Therefore, in many cases, especially at short distances, the multiply reflected images of the light source can be seen in the water below the surface like a reflected picture behind the mirror.

As is well known from other reflection phenomena, e.g. the rainbow or the "heiligenschein", each glitter path is unique in that it "belongs" to the observer. Due to the physical fact, that only those points of the rippled surface appear lit by the light source which, according to the law of reflection, had an appropriate slope, the location of the "sword of the sun" depends crucially on the observer's position. This explains, why Mr. Palomar saw the sword always directed to him.

Ubiquitous glitter paths

Light paths are not only detected on wavy water surfaces. On a rainy day the head- and taillights of cars draw beautiful light beads on and in, respectively, the streets (see Fig. **9**). The fact that streets are not smooth but slightly irregularly rippled brings about a similar situation as on the wavy water. Under certain conditions it is not even necessary that the surface was wet. For instance, smooth floors which have been scratched by use can be excellent displays for glitter paths (see Fig. 10). But also surfaces, which look perfectly smooth, like table tops and metallic plates or lids (see Fig. 11), may show light streaks when displayed under a light source (at best a point source) and thus reveal tiny scratches which cannot be seen by the naked eye. These scratches fulfil the same function as the waves on the water in that their varying slopes provide for appropriate angles for the light to be reflected into the observer's eye.

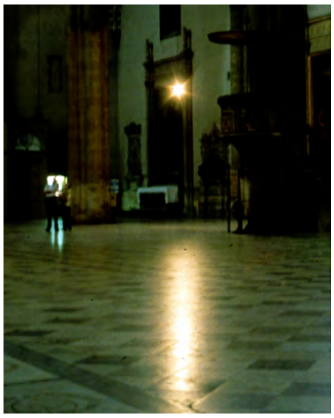

Fig. 10: Light streak on the tiled floor of a church.

To derive the structure of the surface by examining the form of the light paths corresponds in some respect to methods of surface science, where the microstructure of surfaces is investigated by analysing the reflected "light" (not necessarily visible, for example, X-rays, electrons) of a known source.

The more our eyes get trained to detect light paths in the everyday world the more subtle become the phenomena, which will be recognized as such. One example is the well-known light streaks appearing on records which bend in various shapes when viewed from different angles. This phenomenon emerges as well on compact discs, where the white light splits up in spectral colours due to the interference phenomena which become important on this scale.

Up to now we only took into account light paths due to reflection. Transparent plates may also display light streaks when looking through them at a light source. For instance looking through the window pane of a bus or a train to a distant light source this source may appear endowed with a long straight almost vertical light beam. The beams are not caused by reflection but by refraction of the passing light at an array of parallel tiny gratings on the panes oriented orthogonally to the light beams. Due to the transparency and invisibility of the panes the light beams are not associated with the panes but with the light sources. The origin of the scratches may be, for example, grooves caused by the rotating brushes of the cleaning machines.

Fig. 11: Light paths on a lid deformed due to the curvature of the surface.

Looking through the front windshield of a car at a light source one may detect light streaks similar to the reflection beams of a record. Circular gratings caused by the action of the windscreen wiper are the reason.

Fig. 12: Circular light rings around the image of a reflected light source on a spoon.

A rather peculiar class of light paths consists of short light tracks which seem to form concentric circles around the image of a reflected light source on a smooth surface (see Fig. 12). In a strict sense the surface is not smooth but has microscopically small grooves or scratches. If there are many scratches and if they are randomly distributed there will be always short sections of the surface exhibiting a suitable range of slopes for the light being reflected into the observer's eye. For symmetry reasons the sections of the same slope are oriented along a circle around the reflected image. The extent of the illuminated area depends on the angular range of the scratches. Normally, the origin of the randomly oriented scratches is due to abrasion by daily use.

A corresponding phenomenon can be observed when light shines through a scratched transparent plate. The light is refracted at randomly distributed scratches giving rise to similar circular light pattern as in the case of reflected light. Light sources viewed through an airplane window, in most cases, appear surrounded by circular oriented illuminated light lines.

(For further information see Schlichting 1998/99).

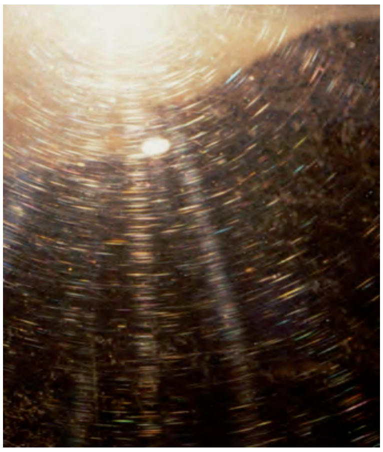

Fig. 13: Circular light rings on an airplane window.

Summary

Starting with the glitter path as a common natural phenomenon which has attracted special attention, especially by painters and poets, it has been shown that there are also interesting physical aspects.

From a physical point of view the glitter path is both simple <u>and</u> complex. It is complex inasmuch as the shape of the reflected light trail is not related in a direct way to a specular reflection of the sun. It can be shown by simple hands-on experiments, at least qualitatively, that the glitter path may be conceived of as a composition of many tiny mirrors irregularly distributed on the water plane. The mirrors are made up of the slopes of the waves.

Against the background of this approach the observer is prepared to detect "glitter paths" in many different contexts, as, for example, the headlight of a car reflected on a wet road or the light bands of a street lamp in a water puddle. Finally, even light paths on totally dry grounds, e.g. on a tiled floor or even those light streaks apparently attached to light sources looked at through transparent media may attract attention.

The problem of explaining complex phenomena within an every day life situation is in most cases not as much due to the complexity of the physics behind them but due to the difficulty in recognizing and elaborating physical aspects in a non-physical context.

Although the physical explanation represents an extreme reduction of a complex, multiperspective application of the simple law of reflection or, in the case of transparent plates, of the law of refraction, this must not necessarily be experienced as a disenchantment. On the contrary, the physical perspective may intensify and enrich our view and thus contribute to detect further interesting related phenomena.

Moreover, according to our experience, both the aesthetical effect of the phenomena and the satisfaction of the learner felt in successfully elaborating a complex problem are a source of a high motivation.

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STUDENTS' SKILLS DEVELOPED BY PARTICIPATION IN THE INTERNATIONAL YOUNG PHYSICISTS' TOURNAMENT

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Extracurricular activities for physics students in upper secondary schools could take the form of participation in international physics competitions. One such event is the International Young Physicists' Tournament (IYPT) which takes place once every year in different countries. The organization of this competition will be described and examples will be given of problems presented for those participating. Since this event involves teams of pupils it differs from the Physics Olympiad which is organized on a strictly individual basis. In addition to the aspect of team work the competition requires some research activities as a preparation for the presentations of solutions to the rather open-ended problems on the agenda. Thus, the skills which must be developed might be different from the ones which are normally emphasized in the ordinary school curriculum.

Introduction

For several decades physics competitions of different kinds have been organized all over the world. In most cases the participating students come from secondary schools, very often pupils in the last grade before entering university. The best known is the International Physics Olympiad, an individual competition which, unlike the sports event, is organized every year in different countries. Other events are regional or national, possibly with invitations for participation by students from neighbouring countries.

IYPT History And Administration

In this paper a team competition called the International Young Physicists' Tournament (IYPT) will be described, in particular with respect to the skills one hopes to develop among participating students. The history of IYPT dates back to 1988 but in the beginning the event was always organized inside the Soviet Union or, from 1992, in Russia. However, from as early as 1979 there was a precursor organized at Moscow State University for secondary school students from the Moscow region.

In 1994, for the first time, it was arranged in a different country, namely The Netherlands. Since then ten countries have organized IYPT with an ever-increasing number of countries participating. In 2004, for the 17^{th} IYPT, Brisbane, Australia, was the host for 26 teams from 24 countries, representing six continents.

Details of the competition structure are strictly prescribed in regulations, whereas the organization itself is ruled by Statutes, adopted in June 2004. The governing body is an International Organizing Committee (IOC) which meets at least once annually, during an IYPT event. The event itself is arranged by a Local Organizing Committee (LOC). Between IOC meetings an Executive Committee handles the issues as decided by IOC. It consists of seven members

IYPT Problems

The 17 problems to be solved by participating teams are nowadays published on the Internet several months before the competition takes place. They are selected by an international group of physicists, consisting of both school teachers and researchers from various institutions, mostly universities. Suggestions for problems to be included are submitted in advance and the group normally has well over 100 problems to choose from. Care is taken to spread the problems over as many subfields of physics as possible. Additional criteria involve the need for problems which require some experimental research and which are by their nature “open”, i.e., they should not have a unique solution but rather be possible to handle from different aspects and thus to give alternative solutions. Physics subfields which are quite frequently found among the selected problems are mechanics, electricity/magnetism and optics. In these cases it is relatively easy for the students to find equipment, to construct models and develop strategies for discussing their solutions.

Over the years it has been shown to be difficult to list problems from certain areas like “modern” physics. Partly this is due to the assumption that many school curricula do not include this subfield, but it is partly also due to logistical constraints, such as restrictions in handling radioactive substances, for instance. In general, it could be added that the selected problems often favour schools with modern laboratory equipment. However, in judging the solutions presented the jury can take into account the ingenuity and creativity of the participants and thus compensate for the lack of equipment

IYPT Structure

The structure of the competition has been developed through the years from the start, but the changes introduced have been small. In each of the five qualifying rounds, called Physics Fights, three, or sometimes four, teams meet and present their solutions to one of each of the 17 problems on the list. A team consists of five members, representing one country. However, the host country can have two teams participating. The same is true about Russia, a privilege having to do with the fact that IYPT was initiated in that country. As another historical remnant the Russian language is still allowed in the discussion; otherwise everything is conducted in English.

Which problem a certain team has to tackle is decided by a so-called challenge from one of the other teams present. There are three roles possible in a round: reporter, opponent and reviewer. The opponent challenges the reporter for one of the problems. The reporter can refuse to accept the challenge, but after a total of three refusals during the five rounds the grading given by the jury will be lowered. After the report of the solution the opponent will scrutinize the solution and point out merits as well as possible weaknesses. The reviewer comments on both the solution of the reporter and the remarks of the opponent. All items on the agenda are strictly timed. The report, for instance, can take no more than 12 minutes, whereas the opposition and the following discussion with the reporting team are allowed a maximum of 15 minutes.

After this first part of a particular qualifying round the roles are changed, and at the end of a full round all three teams have had each of the three roles. If four teams are present the members of the fourth team are called observers; they remain passive during each part of the round. Also this role is adopted by each of the four teams in turn.

The performance of the teams is graded by an international jury, composed of normally 5 to 8 members who are either independent or connected to one of the teams not participating in that particular round. In principle all jury members come from different countries and none of them comes from the same country as a participating team. The grading of the jury is recorded and forms the basis for a decision, after the five qualifying rounds, to select the best three teams who compete in the final round. The rules are different there in the sense that the three teams choose for themselves which problem they want to handle. The choice is made according to the ranking after the first five rounds, the team with the highest ranking chooses first, etc.

Examples Of Problems

Some examples will be given from each of the four last events, in order to show the character of typical IYPT problems. The first was given in Brisbane in 2004 and had the following wording:

Didgeridoo
The 'didgeridoo' is a simple wind instrument traditionally made by the Australian aborigines from a hollowed-out log. It is, however, a remarkable instrument because of the wide variety of timbres that it produces. Investigate the nature of the sounds that can be produced and how they are formed.

This problem was chosen by the Polish team in the final and the solution included presentations of live performances as well as theoretical descriptions of how the sound was produced. The solution of this problem made the Polish team winners.

In 2003 IYPT was organized in Uppsala, Sweden. The winning German team had chosen the following problem:

Heat engine
Construct a heat engine from a U-tube partially filled with water (or another liquid), where one arm of the tube is connected to a heated gas reservoir by a length of tubing, and the other arm is left open. Subsequently bringing the liquid out of equilibrium may cause it to oscillate. On what does the frequency of the oscillation depend? Determine the pV diagram of the working gas.

The city of Odessa in Ukraine hosted the 15th IYPT in 2002. In that event the following problem was chosen in the final by the winning Polish team:

Spinning ball
A steel ball of diameter 2-3 cm is put on a horizontal plate. Invent and construct a device, which allows you to spin the ball at high angular velocity around a vertical axis. The device should have no mechanical contact with the ball.

The 14th IYPT was held in Espoo, Finland, in 2001. The winning team from Slovakia had chosen the following problem for the final:

Thread dropper
One end of a thread is immersed in a vessel filled with water. The other end hangs down outside without contact with the outer wall of the vessel. Under certain conditions, one can observe drops on that end of the thread, What are those conditions? Determine how the time of appearance of the first drop depends on relevant parameters.

What Skills Are Developed?

For participants in the IYPT competition it is evident that certain skills are needed for success. Some of these are also essential for success later in life, if a student chooses to continue to a career in physics research or in teaching.

In the preparation for the competition some experimental research, as well as a study of the theoretical basis for a solution to the problem, is needed. This work would normally be done in a team, sometimes inside the team that appears in the competition. In addition, a literature search is normally performed, and the participants are free to quote suggestions from elsewhere, including from teachers or professional researchers. Already it is clear that to be prepared for the event itself the following skills have to be developed:

Experimental research,
Theoretical study,
Correct references to other results quoted, and
Team work.

The reports are given in English and the time assigned is quite limited. For the vast majority of teams English is a foreign language; some years back no team, in fact, had English as their mother tongue. It is thus essential to learn to present a solution in a clear, convincing and logical way and to be disciplined regarding the time to be used. In addition, the use of modern visual means of presenting a report becomes increasingly important for the outcome. The corresponding skills would be:

To present as clearly as possible the solution suggested,
Using modern means of communication, and
To plan the report within the time given.

In the discussion periods, between opponent and reporter as well as when the reviewer makes comments, great emphasis has traditionally been put on the way possible criticism is formulated. Unnecessarily aggressive behaviour will be punished by the jury. Remarks like “Obviously you have not understood the physics behind your reported solution” do not contribute to effective discussion and must be excluded. Adding the fact that an IYPT event, when hundreds of young students from all over the world meet and associate for a week, calls for certain behavioural attitudes, one might add to the list the need for and development of

Social skills in a broad sense.

The Selection Of National Teams

Different countries have adopted quite different strategies for selecting their national teams. Quite a few organize their own national qualifying competitions in order to find the best team to represent their country. In some cases the selected students are also invited to prepare for their performance in IYPT at a university. Other countries depend on one or a few enthusiastic physics teachers who train and encourage students from their own classes.

The school curricula in different countries also differ substantially, making it more or less difficult to fit in the rather extensive preparation needed for students of the final year in upper secondary schools.

It is clear that if the resulting ranking were the only important outcome for participating teams such different preparation possibilities could appear unjust. However, as in most other instances, it is only fair that those who have the best preparation also obtain the best ranking. In addition, there are certainly many other positive features of participating which compensate for a less successful ranking.
Since in many countries girl students show less interest in physics than boys it is encouraging that a fair number of girls participate in IYPT. Recent years have even seen teams of girls only among the competitors, once from Poland and once from Australia. It is possible that the cross-disciplinary nature of some of the problems is a contributing cause.

Concluding Remarks

After a period of difficulties to find willing hosts for the next IYPT events the situation is now encouraging in the sense that we seem to have a queue of possible hosts for the next five to six years. Thus, in 2005 Switzerland will be the host country, and in the following years South Korea, Slovakia and USA are among the candidates for arranging a new IYPT event.

An international organization, the World Federation of Physics Competitions (WFPC) was recently set up. It held its second Congress in Groningen, The Netherlands, April 14^{th} to 18^{th} of 2004. In the first issue of Vol. 6, their journal Physics Competitions gives a full account of the agenda of this meeting. Both national and international competitions are presented. The impact of events like IYPT on the physics curriculum is discussed by experienced teachers who have also been organizers of different competitions. In particular the paper by Z. Rajkovits and L. Markovich [1] makes interesting comments on these aspects.

I should like to thank A. Nadolny, Secretary General of IYPT, for providing important details, especially concerning the history of IYPT [2].

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[1] Z. Rajkovits and L. Markovich, The influence of international competitions on the everyday physics teaching, *Physics Competitions*, Vol. 6, No 1, 64-80 (2004)

[2] A. Nadolny, International Young Physicists' Tournament (IYPT), *Physics Competitions*, Vol. 4, No 2, 63 – 72 (2002)

CONCEPTUAL DIFFICULTIES ASSOCIATED WITH THE ENERGY CONCEPT AS EXPERIENCED BY SCIENCE TEACHERS IN NORTH WEST PROVINCE OF SOUTH AFRICA

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It is well known that one of the reasons for the poor status of science education at school level locally, is that many science teachers have difficulties with the understanding of science concepts. This study, aimed at investigating science teachers' difficulties with the energy concept, revealed that most of their notions about energy are not scientifically acceptable. The study recommends that as a way of addressing this problem, both the nature of physics and its epistemology be integrated with the subject content in the curriculum.

Introduction

Studies conducted locally revealed that the status with regard to the teaching of science at school level in South Africa is far from satisfactory (Webb, 1992, p423; Smit & Nel, 1994). One of the main reasons for this situation is the fact that many science teachers experience difficulties with the understanding and teaching of scientific concepts due to inadequate training that they received (Bradley & Stanton, 1986, p538). The study reported on here was aimed at investigating conceptual problems that science teachers experience with scientific concepts with particular focus on energy and related concepts.

The topic of energy has received increased attention in science education research in recent times. However, evidence is mounting that despite all the attention that the topic of energy has received, all is not well with the teaching of the concept. The much hoped for revolution in its teaching has not taken place (Taber, 1989, p58). By virtue of the cardinal importance of the energy concept at all levels of the science curriculum, it is important that more efforts be made towards understanding learning difficulties associated with the concept.

The empirical survey

The empirical investigation was done on a group of 65 GET (General Education and Training) teachers and 82 FET (Further Education and Training) teachers enrolled in science teacher upgrading programs conducted at the Potchefstroom campus of the North West University. Teachers in both these groups were in possession of three-year teaching qualifications and taught at schools in disadvantaged communities in the North West Province. Information in the empirical survey was obtained by means of a questionnaire, which was administered to both groups of teachers. The questionnaire consisted of 31 items and was focussed on probing conceptual difficulties that teachers experience with the understanding of basic concepts related to energy.

The items in the questionnaire were grouped into six categories: *the meaning of energy and its nature* (items 1, 2, 3, 4, 16, 17, 18, 19, 20)*; energy conservation* (items 5, 6, 7, 28)*; sources of energy* (items 8, 9, 10)*; the relation of energy with other physical concepts* (items 13, 14, 15, 23, 24)*; electricity* (items 25, 26, 27, 29)*; kinetic energy and potential energy* (items 21, 22, 31).

The items included in the questionnaire were as follows:

1. Do you experience difficulties with the understanding of the concept of energy?
2. Is the energy concept a difficult concept for you to teach?
3. Are you satisfied with the manner in which the energy concept is treated in the textbooks that you use?
4. Do you think that the understanding of the energy concept is of critical importance in the understanding of how natural phenomena occur?
5. State the law of energy conservation.
6. In your own words, what does the law of energy conservation mean?
7. A perpetual motion machine is a machine that will continue to move or to do work, without any further energy input, once it is started. Mark the statements about a perpetual motion machine that you think are correct. You may mark more than one of the statements below.

A. To date, no one has been successful in developing a perpetual motion machine.
B. It is impossible to develop a perpetual motion machine
C. It is possible that in future some bright person may develop a successful perpetual motion machine.
D. I am unsure about all the answers given above.

8. What is the main (primary) source of energy on earth?
9. Where does the primary source of energy mentioned in No. 8 above gets its energy from?
10. What would happen if this source of energy suddenly stops to release its energy?
11. In your own words explain what *heat* is.
12. Which of the following statements about heat is correct?

A. Heat is a substance like a fluid that can move from one substance to the other.
B. Heat is not a substance and has no material attributes
C. I am not sure as to whether heat is a substance or not

13. In your own words explain the relationship between *energy* and *heat*?
14. In your own words explain the relationship between *energy* and *work?*
15. In your own words explain the relationship between *energy* and *power?*
16. Explain in your own words what energy is.
17. Which of the following statements about energy are correct?

A. Energy is a substance like a fluid that can move from one substance to the other.
B. Energy is not a substance and has no material attributes
C. I am not sure as to whether energy is a substance or not

18. Can the magnitude of energy have a negative value?
19. "If scientists were not able to measure and calculate amounts of energy, the energy concept would still be of major importance in science." Do you agree with this statement or not?

20. Suppose you are given an opportunity to ask any question about energy. What is that that you would like to know about energy that is not clear to you?

For question 21 and 22, consider the situation whereby a ball is thrown vertically upwards.

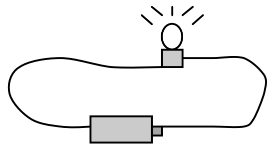
21. What happens to the magnitude of gravitational potential energy of the ball as it goes up?
22. What happens to the magnitude of gravitational potential energy of the ball as it falls back to the thrower's hand?

Question 23 and 24 refer to the following statement:

"A man stands for an hour while holding a heavy toolbox in his hand and is getting awfully tired doing this."

23. In everyday life, would people say that the man does work to hold the box?
24. According to physics, does the man's hand do work on the box?

Consider the circuit diagram below in answering items 25 - 29



25. What is the function of a cell/battery in an electric circuit?
26. A cell is marked 1,5 V. What does this reading imply?
27. A voltmeter connected across the bulb reads 1,4 V. What does this reading imply?
28. Is energy conserved in the sketched electric circuit when the switch is on?
29. What would you say is the prime function of *any* electric circuit? In other words, what is the significance of connecting an electric circuit?
30. A bucket of sand weighing 120 N is raised from the ground to a 5 m high scaffolding.
    (a) What type of energy does the bucket of sand have when it is on top of the scaffolding?
    (b) Calculate the amount of energy gained by the bucket of sand.
    (c) The builder drops the bucket of sand as he tries to take it off the hoist. Determine the kinetic energy of the bucket of sand as it hits the ground.
31. A force of 20 N is applied to pull a box of mass 10 kg over a distance of 5 m across a floor. Calculate the amount of work done on the box.

Discussion of results

In evaluating teachers' performance in this survey, each of the completed questionnaires was scored out of 29, with one point allocated to each scientifically acceptable response. The other questions (1, 2, 3 and 20) were not included in this scoring as they do not have right or wrong answers. The results (in percentages) are shown in figure 1. The percentages are on the vertical axis and the item numbers are on the horizontal axis of the graph. The average score of all the teachers who completed the questionnaire was found to be 38 %, with a standard deviation of 3.75. The average score of the GET teachers was 33 %, while that of the FET teachers was 42 %. The standard deviations for the GET and FET groups were 3.45 and 3.62 respectively.

The results depicted on the graph below (Figure 1) revealed that generally the teachers who participated in this study experience conceptual problems with regard to the understanding of energy and related concepts. The average performance of 11 out of 29 is far below what was expected. These results pose questions about the quality of professional training that these teachers received prior to this survey and their ability to perform effectively as science educators. The teachers did not seem to master what they are supposed to teach.

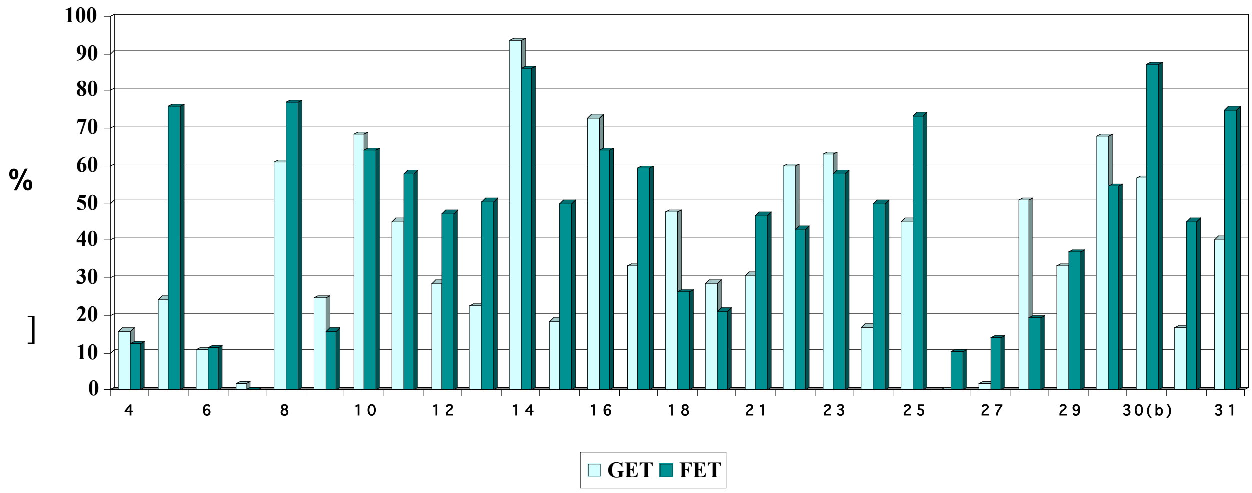


Figure 1

Item 20 in the questionnaire was an open-ended question that prompted teachers to state questions about anything related to the concept of energy that they would like to know. Teachers posed a wide range of questions that are reflective of the nature of difficulties that they experience with the energy concept. These questions were grouped according to the six categories of items in the questionnaire and their percentage distribution amongst these categories were such that most (45 %) of the questions posed by teachers related to *the understanding of the energy concept and its nature* followed by *energy conservation (17 %)* and *energy sources (17 %)*.

It can be deduced from this finding that as far as energy is concerned, most of the teachers' problems related to the basic understanding of the intrinsic nature of energy: *What actually is energy? Why is the energy concept important in science? Does energy actually exists or is it just a fictitious idea? Is energy a substance or not? Why can't energy be measured in absolute terms?* Apparently, learners and teachers have difficulties with the understanding of the nature of energy because it is a conceptual entity and has no material properties (Glashow, 1994:105).

These results are corroborated by the graph in figure 2 below, which depicts the average scores of both groups of teachers on the six categories of items, according to which the categories; *the* *understanding of energy and its nature (Gr1)* and *energy conservation (Gr2)* are amongst the lowest scored.

From the results depicted above, it is clear that, teachers who took part in this study, experienced problems with the understanding of the concept of energy at the time of the survey. Hereunder, is a summary of their conceptual difficulties as manifested in their responses. The problems are grouped according to the six categories of the items in the questionnaire. However, no apparent conceptual difficulties that relate to Gr6 category (Kinetic and potential energy) were revealed by this study.

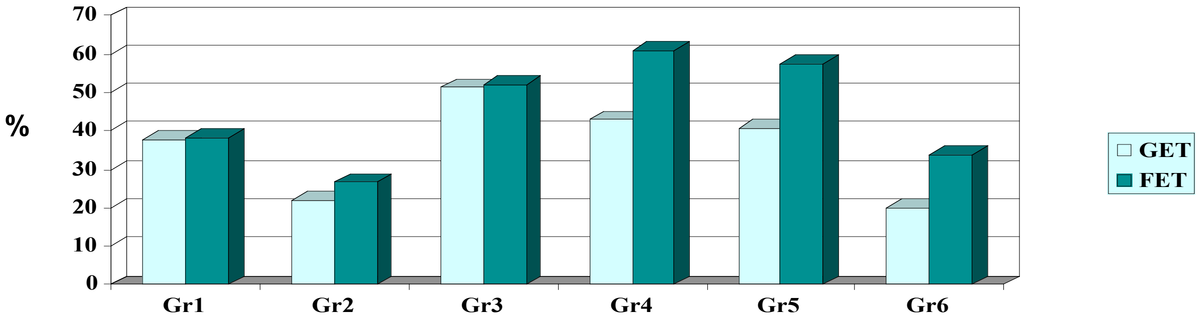


Figure 2

The understanding of energy and its nature (Gr1)

- Energy is something that exists in material sense (Bamberg *et al*, 1993, p25; Bunge, 2000, p457; Solomon, 1982, p416; Warren, 1982, p297; Watts, 1983, p216)
- Heat is perceived as a source of energy.
- Energy is just a luxury item that makes our lives easier (Duit, 1981, p296)
- Heat is perceived as a material substance that can move from one object to the other.
- Energy can be contained (by objects) and released in a material sense (Mclldowie, 1995, p229).
- The magnitude of energy cannot be negative.

Energy conservation (Gr2)

- Energy conservation means the practice of using energy sparingly without wasting it (Boyes & Stanisstreet, 1990, p51; Duit, 1981, p299).
- Energy is conserved when the amount of energy in a substance does not change.
- Energy is not conserved in DC circuits because the battery gets flat if connected long enough (Wesi, 1999:170).
- Energy is not conserved in DC circuits because it is converted into other energy forms.

Sources of energy (Gr3)

- The energy produced by the sun is attributed to mysterious natural processes that cannot be understood or accounted for.
- The sun is not necessarily crucial to life on earth. Should it cease to give off its energy there may be some changes on earth but otherwise life would still go on, as there are other alternative sources of energy, or other forms of "life support".

The relation between energy and other physical concepts (heat, power, force, work) (Gr4)

- Energy and power are perceived as being similar and are used interchangeably. "Energy is power to do something".
- Heat is perceived as a consequence of application of energy.
- Heat is something that carries energy.
- Power is the strength to do something.
- Work can be done even when no movement is involved (De Berg, 1997:524).

Electricity (Gr5)

- Batteries are perceived as sources of current.
- Voltage is something that can be contained inside cells in a material sense.
- Voltage is something that flows in electric circuits.
- Energy is something that flows in electric circuits.
- The prime purpose of connecting electric circuits is to conduct current.

In another study by Wesi *et al* (1999, p170), that focussed on science teachers' conceptual problems in electricity, it was revealed that many science teachers who come from a similar background as those who participated in this survey, harbour alternative conceptions similar to those generally exhibited by learners. This was found to be the case also in this study, as most of the conceptual difficulties mentioned above are generally experienced by learners. This finding suggests that more needs to be done to address the lacunae in many of our teachers' understanding of science.

Conclusion

In conclusion, it can be suggested that the very low performance by teachers in this survey is not only indicative of the inadequacy of the training that they received, but also indicates the difficulty and elusiveness of the energy concept (Bunge, 2000, p457; Ward, 1986, p797). It is evident from teachers' responses to the questionnaire that they tend to memorize unconnected bits of scientific information, without forming a coherent understanding of the concepts involved. There is apparently no demand by the curriculum currently taught, for them to go beyond mere memorisation of scientific facts, laws and definitions. This was demonstrated by the ability of many of them to state the law of energy conservation correctly while they fail to explain what it means.

According to Papacosta (2000, p64), physics concepts are better understood when they are not viewed by themselves, but from historical perspectives, as part of the development of physics as a whole. Bybee (2000, p33) also argues that the understanding of the nature of physics and processes that led to the development of physical theories and laws provide learners with intellectual structures and logical associations that facilitate learning. The implication is that more attention should be paid to aspects of the nature of science and epistemology in teaching at school level and in teachers' training programs. Efforts by the South African Department of Education to incorporate these into the newly introduced outcomes-based curriculum are commendable (Department of Education, 2002). However, serious attention still needs to be paid to what exactly should be taught.

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QUANTUM MECHANICS FOR EVERYONE: CAN IT BE DONE WITH TECHNOLOGY?

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In many pedagogical strategies hands-on activities with real apparatus precede any introduction of new concepts. These teaching-learning strategies are well suited to introductory level material. However, abstract topics present additional challenges in keeping the pedagogy consistent with knowledge about how people learn. Visual Quantum Mechanics includes teaching/learning units to introduce quantum physics to a variety of audiences ranging from students who normally would not study these topics to undergraduate physics majors. Interactive computer visualisations are coupled with hands-on experiences. Our goal is to enable students to obtain a qualitative and, where appropriate, a quantitative understanding of contemporary physics. Included in the instructional materials are student-centred activities that address a variety of concepts and applications to devices such as the light emitting diode. Thus, Visual Quantum Mechanics allows a wide range of students to begin to understand the basic concepts, implications and interpretations of quantum physics.

Introduction

Frequently, quantum mechanics is taught only at the end of a first physics course -- if it is taught at all. The reasoning is that quantum mechanics is a very abstract idea without much practical purpose. Therefore, the students can't understand it until they have learned all the rest of physics -- at least that is the assumption. We have been working to change that way of thinking and have quantum mechanics integrated throughout the first physics course rather than just tacked on at the end. To make this change we have been developing a hands-on approach to learning and teaching quantum mechanics.

We certainly believe that students learn by doing; they do not learn by sitting in lectures. Concrete experiments come before the theory. Students do something first, so they have something to think about and explain. Application of the new concepts comes immediately after the theory. And, those applications should be hands-on and interactive in some way. We use an approach (called the learning cycle) that was developed by Robert Karplus many years ago. (Karplus, 1977) Basically we follow this format in everything that we do.

The students for whom we are aiming are middle to upper secondary school and beginning college students (approximately 14-20 years old). They have little science or math background and a low interest in science. We must have hands-on activities if this group is to study quantum mechanics. Our general goals, then, are to teach quantum mechanics to students who do not normally study it and to minimise both the mathematics and physics prerequisites.

We use computer visualisation that is highly interactive as well as hands-on activities. The hands-on activities are with real stuff. Computer visualisations are still hands-on; the students' hands are on the keyboard and the mouse; their minds are on the content. The students must think and manipulate; they are not just watching animations or simulations.

We have put all of this material together in a package which includes written materials. Some people tend to believe that if you use the computer, everything will be on the computer. We do not do it that way. The students use work sheets. The important part of these sheets is not the words; it is the blanks between he words. The students are expected to write something in those blanks. So, the students, read, write, do activities, and work with the computers -- all in one integrated approach.

Device Orientation

Sometimes quantum mechanics is taught in such a way that students learn some quantum mechanics and never know what it is good for. We did not want that situation, so we decided to introduce some devices that are quantum mechanical. Students should recognise these objects and see them in their everyday life. The light emitting diode (LED) is one. They are everywhere. Although students do not know the name, they have seen them. By explaining the properties of LEDs the students learn that LEDs are different from other light sources.

We occasionally use devices that students may have heard about and may have seen pictures of, but they certainly haven't encountered. The scanning tunnelling microscope is the best example. We do not expect students to use a scanning tunnelling microscope although it is possible for some students to build one. The students that we are addressing are not likely to be able to build such a device. So, in this case, we use a combination of a simulation and an interactive program.

We also use a variety of solid light sources. Infrared detector cards are a rather interesting example. They are fairly recent development -- at least fairly recent for inexpensive versions. TV repair people need to know if a television remote control is emitting infrared. How can they do that? It is rather simple if they have a video camera. The camera responds to IR and shows a bright spot where the IR is emitted. So, every TV repairperson needs a video camera, and he/she can find out whether light is coming from the remote control. But that's rather expensive. Another way to detect IR is with rattlesnakes, which are sensitive to infrared. So, every TV repairperson could have a rattlesnake. But that is rather expensive in a different way. However, one can buy, for about US$5-6, a little card that responds to IR by emitting visible light. Thus, it absorbs low energy photons and emits higher energy photons.

In this paper I will not present details about the IR card. However, I will give you a hint about how it works. An IR detector will not work if it has been in the dark for a long time. If it is then exposed to visible light, it will start detecting infrared.

The Star Trek Transporter is also a quantum mechanical device. I know that because I read the *Star Trek Technical Manual*. (Sternbach & Okuda 1991) I found that the Transporter has a component called a Heisenberg Compensator. When one of the writers for Star Trek was asked, "How does the Heisenberg Compensator work," he responded, "Very well."
These and several other devices are introduced to students. In each case we show how the devices are related to quantum mechanics. Further, the students learn how the devices work at the atomic level.

Instructional Units

The Visual Quantum Mechanics instructional units are relatively short. Each one requires approximately 10 hours of class time. And, they can be inserted in various places within the physics course --- not just at the end. *Solids & Light* concentrates on the LED; *Waves of Matter* introduces atomic spectra and the basic wave properties of matter; *Seeing the Very Small* concentrates on the scanning tunnelling microscope, and *Luminescence: It's Cool Light* looks at many different light-emitting devices. In this paper I will concentrate on the *Solids & Light* and *Waves of Matter* units. More details have been published in recent journal articles. (Escalada, Rebello, & Zollman, 2004; Zollman, Rebello, & Hogg, 2002; Jolly, *et al*., 1998)

The Solids & Light Unit

Solids & Light is our longest unit and requires about 12 hours for the students to complete it. The students require very few prerequisites. They need to know conservation of energy, that light is a form of energy and how to record a voltage in a circuit that has already been made for them. We do not care if they know what voltage is. We say voltage is related to a measurement of energy. That is all they need to know for this unit. The students' circuit has a battery, a place to put LEDs, a place to put an incandescent bulb, terminals to connect a voltmeter, a little potentiometer (called a trimmer pot in the electronics business), and a resistor to keep students from burning up LEDs.

The students begin by exploring the response of the LED to energy (voltage) changes. As they increase the voltage across the LED, it turns on. The students determine the

TABLE 1: The threshold voltages for

Colour of LED	Threshold Voltage
Red	1.40 volts
Orange	1.55 volts
Yellow	1.60 volts
Green	1.76 volts

minimum voltage for each LED to turn on. They discover that the colour of the LED determines the energy at which it turns on. Infrared LEDs require the lowest energy, red the next lowest, and so on to blue, which requires the most energy. (See Table 1) They also look at and record the spectrum of each LED.

So the students can compare LEDs to other light sources we provide them with incandescent lamps that are used on Christmas trees in the U.S. These lamps are small, have different colours, and are very inexpensive. They also emit light of different colours

Students do the comparisons. They find that the threshold energy depends on the colour for the LED but not for the incandescent lamps. The direction that the device is placed in the circuit is important only for the LED. One obtains a coloured light from an LED that is clear when it is turned off. With the Christmas tree light one knows the colour before the light is turned on...

The next hands-on activity is to look at spectra of gases. The students do the hands-on experiment. They observe and record the spectra. To relate the observations to energy changes in the atom we have developed a computer program (Figure 1). They use this program which simulates the spectrum. They "do" the experiment just like they did it before so they have to put the spectrum tube in the power supply and out comes the spectrum. Before the students do this activity, we introduce the concepts that atoms change energy to emit light. Now they are supposed to create energies and transitions so they can recreate the spectrum. Figure 1 show how a transition can create the blue line on the right. Thus, the blue line in the lower spectrum matches the real (upper) spectrum.

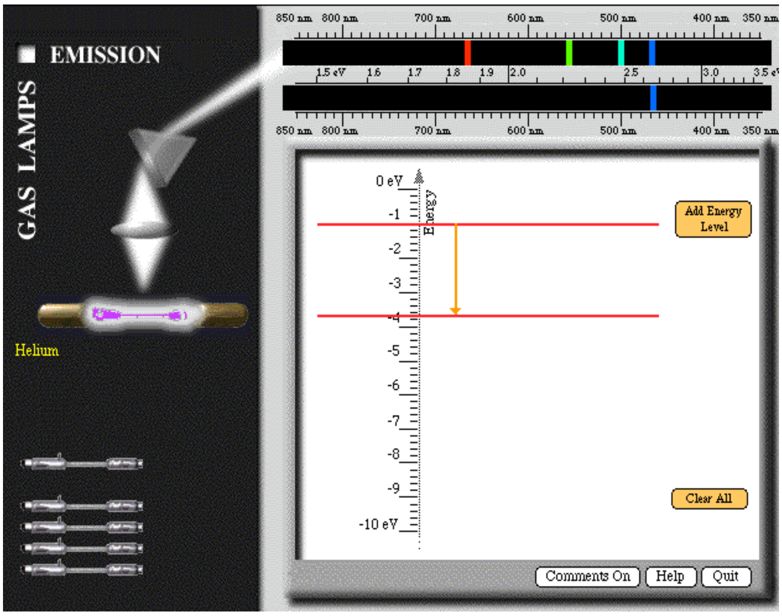

FIGURE 1: A screen capture from Spectroscopy Lab Suite. An on-line version is available at http://web.phys.ksu.edu/vqm (Requires Macromedia Shockwave plug-in.)

We have observed an unusual first step for a wide range of students. They say, "I see that I have a line at 1.9 eV. So, I will move an energy level to -1.9 eV. Then, I will have created one line in my spectrum." . (The negative numbers don't seem to bother them.) In effect the students are equating the energy of an emission line with the energy of a state in the atom. We address this conception quickly by using the computer program to discuss transitions.

Students arrange the states and transitions in several ways. Some students will start all of their transitions from one initial state and have different final states. Others will choose one final state and have different initial states. A few students will end up with several different states, each pair having a separate transition. In class I have them walk around and look at each other's computer screens. They see how their model differs from others. Then, I challenge them to discuss which one is right based only on the information that they have from this experiment. Someone always says, "Going to one final state is right, and the final state is supposed to be at 3.4 eV." I will say, "Well how do you know that?" The response usually is, "Well, the chemistry teacher told me it was right."

One of our objectives is to discuss models. Based on the information from their observations only, they do not know which of the models is correct. They only know that the transitions are important. If one student has a large number of transitions with many different energy levels, then the teacher might be able to say, "Oh, but another which you didn't draw could occur. That spectral line would be visible, but we don't see it." So, some possibilities can be eliminated but many cannot. The idea of what a model is and what is acceptable based only on the information that one has is an important part of what we are teaching.

The next step is for students build the LED spectra, a band of colours instead of individual lines by using the gas spectrum program. The students must place energy levels so that they create a band of light in the spectrum instead of individual lines. They learn that they need a large number of states very close together. Once they have done that activity, they use another program to investigate the relation among the width of the bands, the energy gap between the bands and the LED spectrum.

Now the students have seen why solids emit colours and how the colours depend on the properties of the solid. They still need to explain the directionality and the threshold voltage. We have another interactive program that addresses these issues. The students virtually repeat the experiment that they completed as the first exploration. The computer experiment has a voltmeter, a battery, a voltage control and LEDs. They are manipulating all the variables that they did in the real experiment. The program has an added feature. On the screen are the band gap, the conduction band, valence band and the spectra. So they repeat the experiment and see how these properties change as they vary the magnitude or direction of the voltage.

Now, we have come back to where we started. "What are these LEDs and why are they different from the rest of the light emitting devices in the world?" By using hands-on experiments and hands-on interactive programs the students now understand energy levels models for light emission and how to apply these models to gases and LEDs.

The Waves of Matter Unit

Another unit, *Waves of Matter*, teaches some basic concepts of the Schrödinger approach to quantum mechanics. This unit is similar in some ways to the material that you might find in a beginning quantum mechanics book when the author introduces one-dimensional quantum mechanics. The biggest difference is that we do it without most of the equations. We do present the de Broglie equation, but not Schrödinger's Equation. Instead, interactive visualisations are used.

Most of the students' efforts are in using *and interpreting* visualisations of wave functions. After observing interference of light by using a double slit, we move to particles and double slits. We do not expect most students to have an electron diffraction machine available, so we have a simulation. The students play with this program and explore changes in the interference patterns.

The students work through several activities about interpreting wave functions. One of the most important is an introduction to sketching wave functions qualitatively. They work with only one dimension, and we introduce some steps that allow them to sketch wave functions without solving a differential equation. The idea here is much the same as it is in a one-dimensional quantum mechanics course. For example, we discuss continuity of the wave function across a boundary. We use an argument that we have already established -- that the wave function is related to the probability as seen through the diffraction experiment. If you approach a boundary, you expect the probability of finding the electron at that point to be the same whether you come from the left or the right.

One activity leads to the idea of discrete states in quantum wells. The *Wave Function Sketcher* program enables students to match wave functions visually at boundaries. They find that if they pick a random energy for a particle in a square well, the wave function does not fit at both boundaries. They get the

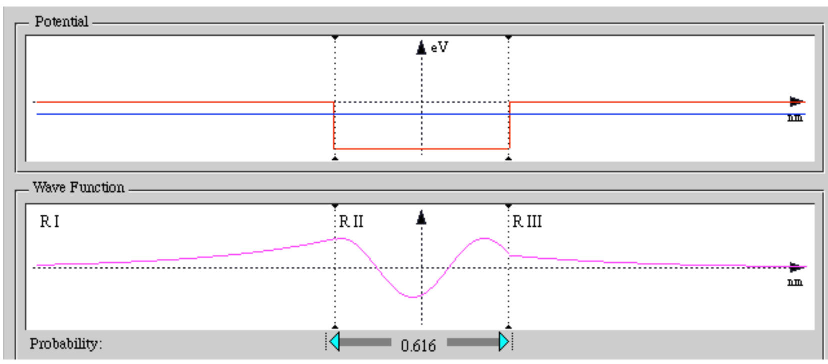

FIGURE 2: An attempt to sketch a wave function for a well.
For this wavelength the student cannot obtain smoothness at

functions matched up on one side, then try to meet the conditions on the other side. They can't do it (Figure 2). Only for certain energies can the meet the boundary conditions on both sides.

Once they have done this activity, they finally get to Schrödinger's Equation. They never see the equation. The machine solves it and shows solutions for bound states. The students can also ask the computer to search for acceptable energies. Now, they see how the wave nature of matter explains the discrete spectra which they have observed.

Other Instructional Units

Two other units treat other aspects of quantum physics. Luminescence: its Cool Light guides the students through activities about a large number of different light sources. The emphasis is on quantized energy states and energy bands and gaps. Seeing the Very Small focuses on quantum tunnelling as it is applied to the scanning tunnelling microscope . The students see how tunnelling can be used to map atoms on a surface and to move atoms one at a time.

Evaluation

The units are being used in secondary schools and in colleges throughout the U.S. and elsewhere. We do not know all the places where they are being used. We have distributed materials to people in Southeast Asia and throughout various parts of Europe as well as the U.S. Most of our reports, however, have come from the U.S. Students' attitudes toward these materials are very positive. They frequently make comments like, "I really like this better than our regular physics. Can we keep doing it?" Our staff have observed teachers using the materials in a variety of different schools. The students are positive; they interact with the materials and each other. Further, our testing indicates that they are learning the material.

Most of the teachers are also positive. A few are not. We certainly have the problem that many teachers do not have a very strong background in quantum mechanics. Even though we are approaching quantum mechanics in a much different way than it is normally taught, some teachers still feel uncomfortable. Building the teachers' confidence is very important.

Some teachers decided that it is too much trouble to have the students work in a hands-on mode with all of these programs. So, they just showed the programs to the students. In these cases learning decreased; attitudes decreased; everything decreased. Hands-on activities make a difference. Of course, we should not be surprised because we built the material for the students to use; not for the teacher to talk about. Overall, it seems to be working rather well.

We are frequently asked, “Are they learning better than with other methods?” Unfortunately, we cannot answer this question. Our primary goal is to teach concepts that our targeted audience have not attempted to learn because physicists generally consider the material too difficult or too abstract for this audience. No other materials which approach the same concepts are available, so we cannot make comparisons.

However, we have looked at learning and addressed the question, “Are they meeting the learning goals which we set out?” In this case we conclude that the students are learning, and they are learning contemporary physics concepts which were not accessible to them by other means.

Availability

The materials are sold in the US by Ztek (http://www.ztek.com) Many of the programs are available on-line for evaluation at http://web.phys.ksu.edu/vqm

The next step

We are now beginning an effort to extend the teaching of quantum physics to future physicians with a project called Modern Miracle Medical Machines. Many of the diagnostic devices which are used by physicians have their technological foundation in contemporary physics. To understand techniques such as magnetic resonance imaging (MRI) and positron emission tomography (PET), students require knowledge of nuclear and quantum physics. Thus, these instruments can provide motivation for future physicians to study contemporary physics. We will build on Visual Quantum Mechanics and create instructional materials for the physics course that is taken by students who wish to study medicine. In addition to MRI and PET, the materials will treat the basics of medical imaging with x-rays, CT scans, and ultrasound. We may also create units on some treatment procedures such as laser surgery and ion beam cancer therapy. The Web site for this effort is http://web.phys.ksu.edu/mmmm

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RECOMMENDATIONS ARISING FROM THE CONFERENCE

In some cases, recommendations were put forward but not fully debated. In other cases, there was some disagreement about the wording or even inclusion of some of recommendations. Nonetheless, all the recommendations that were proposed have been included here in order to stimulate further discussion in the Physics education community.

STRAND 1 (new): Computational Physics

1. Since computers constitute a major tool for scientific investigation, it is important to include computational physics in contemporary courses.

2. We encourage introducing computational physics at first year university level in order to excite students about computing, and getting them to perform numerical experiments without distracting them too much from their main physics course.

3. We need to allow for a balance between analytical and computational approaches.

4. Teachers and curriculum developers should identify experiments that lend themselves to substantial theoretical and computational investigations, especially those that unify underlying physical principles.

STRAND 2: Blurring the boundaries
Relationship between physics and other disciplines

Physics teaching might benefit from the following:

1. Acknowledging alternative world-views.
2. Making students aware of alternative worldviews could be achieved in a single discussion or as a background discussion, which contributes when appropriate. The level of the discussion is audience dependent. At the introductory physics level the preferable approach to employ is the “bottom-up” one. However the “top-down” approach should be mentioned. (See paper by Ellis for definitions.)

3. At present the “top-down” approach is normally not included in physics instruction. Perhaps this should be changed, for example, by addressing the relationship to other disciplines: biochemistry, chemistry and engineering. This could clarify the status of physics within a larger picture of science and thereby help to define areas of physics validity.
4. A “top-down” perspective in presenting physics content is useful and perhaps even necessary. This is because many systems in physics exhibit a large amount of complexity that cannot, at present, be explained by physics. Perhaps physics will never provide an appropriate description for these complex systems.
5. We usually keep human will separate from a set of deterministic laws of nature. Having exposure to an alternative point of view may be helpful for certain students and teachers.
6. Any physical theory constructed so far, including those historically surpassed, might be labeled “effective”.
7. When we discuss physical theories, we should be aware of the appropriate scale of phenomena, which corresponds to the area of validity of the theory. We should also be aware that there is no all-encompassing, universal theory. Thus, a more fundamental theory might not be appropriate to describe a particular phenomenon. For example, application of classical or quantum mechanics is determined by a combination of parameters of the problem: low or high speeds (compared to the speed of light), as well as small and large distances (compared to the size of the atom):

	Low speed	**High speed**
Large distances	Classical mechanics	Relativity
Small distances	Quantum mechanics	Quantum Field Theory

8. When addressing a certain phenomenon in physics, one should not ignore perspectives of other disciplines (chemistry, biology, etc.) on this phenomenon.

STRAND 3: Different strokes for different folks
Which groups of students need what kind of physics

This strand was only discussed in terms of what physics should be taught to physics teachers. More discussion is needed in future about what physics should be taught to other student populations, including future doctors, engineers, physicists and non-scientists.

Recommendations	Elaboration
1. There should be a variety of general (introductory) physics courses to cater for the different groups of student population	Different types of physics courses include: _ Calculus based, such as defined by Halliday and Resnick for physics and engineering students _ Astronomy _ Qualitative physics _ Physics for service courses _ Physics courses that incorporate topics reflecting types of physics being done by local physicists. However for all the courses, physics courses should offer something unique, different from what is offered in other disciplines.
2. Data on student learning difficulties should be used as a guide to physics teaching at a particular level.	Data is essential to address student learning difficulties. Particular emphasis should be placed on cognitive difficulties experienced by students. The questions/instruments used in collecting data should be culturally sensitive.
3. Establish a database that focuses on the pedagogical approaches that can improve physics education.	Careful consideration should be given when collecting data, as some teachers are tempted to omit certain topics or sections which are classified as being "difficult".
4. Teachers should be an integral part of the curriculum development process.	
5. Teachers should learn how to evaluate student learning difficulties in their own classrooms.	A teacher who knows his/her learners well will be able to determine which topics they have difficulties with.
6. Curriculum for physics teacher education should include an integrated	

exposure to history, epistemology, appropriate content, including the contributions of local scientists, laboratory teaching methods, the outcomes of relevant physics education research and the discussion of new teaching practices.	

STRAND 4: Origins and ways of knowing

History and philosophy of physics, epistemology

Recommendations	Elaboration
1. It is proposed that the undergraduate physics curriculum include the philosophy and history of science.	Philosophy helps explain to students the nature of physics as understood and practiced by contemporary physicists. Through epistemology students understand the meaning of physics, where it comes from and how we know it. *The philosophy of physics can help students understand the need for operational definitions of physical concepts, the status of fundamental and derived concepts and laws, the validity and reliability of physical knowledge and the role of theory, enquiry and experiment in physics knowledge.* History helps students understand that physics is man-made. History reveals the human side of physics, factors that make people become interested and enthusiastic about physics. Incorporating history can motivate students to study physics by exposing them to the variety of reasons people have become interested in gaining physical knowledge in the past.
2. The kind of philosophy/history of science that should be adopted is one that promotes critical thinking and brings students closer to the process of doing science.	Discussing why particular experiments that have been conducted are of paramount importance is useful.
3. The teaching and learning of physics should be carried out in a manner that reflects the culture of	Students need to be placed in situations that allow them to see that there is more than one valid way to see and interpret physical

Physics.	phenomena. Physics training should enable students to make valid predictions and to apply scientific reasoning and physical principles to novel situations rather than just searching for the right formula and plugging in numbers in the name of problem solving. Physics teaching and learning should focus on helping students develop the physical reasoning skills, sound understanding of physical principles and ability to think independently needed to solve novel problems starting from fundamental principles.
4. The teaching of physics should reflect the presence of a hierarchical structure in the discipline of physics	Structures provide the connection between the different components of the physics content to be learnt by students. Structures should enable students to see the unity of physics in the diversity of its content. Revealing how physics knowledge is structured can help students to think deductively starting from fundamental principles or inductively starting from the results of observations and experiments.

STRAND 5: Skills

Skills needed for and developed by physics, e.g. cognitive, mathematical, experimental, entrepreneurial

Skills that should be developed include:

1. Commitment to seek understanding.

2. Curiosity about nature and scientific process skills.

3. Ability to use the methods of physics to gain and apply knowledge, i.e. experimentation, development of theory, critical thinking and physical reasoning.

4. Awareness of the fact that the interpretation of a physical phenomenon might involve the use of either mathematical or qualitative models.

5. Ability to understand the difference between inductive and deductive reasoning.

6. Ability to reason, give physical meaning to equations, and read carefully.

7. Ability to evaluate one's own level of understanding.

8. Ability of students to identify the basis of their knowledge of physical phenomena. For example, students should be able to distinguish between when something is an experiment, definition or prediction based on a hypothesis or theory.

9. Ability of students to exemplify how to explore and examine concepts (from a written exposition by a historical figure to the exploring of the changes in a mathematical solution when a parameter is changed).

10. Developing broad content base (skills cannot develop in a vacuum)

11. Ability to estimate using order of magnitude calculations or simple measurements.

12. Ability to solve real problems that affect people and society, not merely carry out routine exercises.

13. Ability to communicate one's ideas to others in writing and orally.

14. Ability to perform dimensional analysis.

STRAND 6 (including original strand 1): Conceptual organization and avoiding fragmentation

Integrating physics topics and selection, sequencing and development of concepts to increase learning

1. A small number of fundamental principles should be emphasized in courses so that students can gain an appreciation for the way that a few principles can explain many phenomena.

2. Help students learn to explain phenomena and theories at different levels and be able to defend their ideas.

3. Design courses so the students develop a coherent conceptual framework.

4. Teachers need comprehensive support materials and professional development opportunities. These courses, workshops, instructor guides, textbooks, and training manuals should be appropriate to the local situation.

5. Teachers and curriculum developers must develop explicit goals, and then design courses and materials that reflect these goals. Furthermore, it is extremely important that evaluation instruments be used to assess the degree of achievement of these goals on a continuous basis.

STRAND 7: Physics for today

Incorporating recent physics developments, technological applications

To be developed:

1. It is recommended that exposure to one or more contemporary topics in physics be incorporated into introductory physics courses. Examples of such topics include quantum mechanics, relativity and non-linear dynamics.

2. Ways to introduce students to contemporary physics could involve attending colloquia, reading popular books, and even science fiction.

3. The contemporary topics should be integrated with classical topics in such a way that both the unity of physics and the distinctive features of the topic are made apparent to students. The topics should also help students realize that physics is continuously developing and is not static.

4. Seek a balance between quantitative and qualitative reasoning in physics courses as they are important in both classical and current physics endeavors.

5. Help students understand that physics is about both the everyday world and a beautiful world of theory and observation that is beyond our immediate senses.

6. Assign projects as a way of motivating students and helping them understand the nature of original scientific invention.

7. Teachers need preparation in contemporary topics in order to help their students learn about them.