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At the most trivial level, mistakes or wrong information in texts can generate misconceptions, but that is not my concern here.

Although language is part of the structure of knowledge, there are some kinds of misconceptions that can be traced simply to the orthodox language of physics, without reference to the overall structure of the subject. Because physics is reductionist in its approach to the world and its knowledge is organised hierarchically, other kinds of misconceptions can arise from the structure of the knowledge and the associated traditional teaching sequences. Among those aspects I include the use of simplistic examples and idealised models as well as the tradition of progressing from the simple to the complex and from special cases of principles to more general formulations. All of those features are represented in standard physics texts.

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Overcoming Misconceptions by Challenging Text-book Orthodoxy

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INTRODUCTION

My concern with the problem of misconceptions and text books is part of a broader plan to improve the introductory university physics curriculum. I will argue here that some aspects of orthodox physics do nothing to overthrow some kinds of naive preconceptions and that they can also actively introduce new, learned, misconceptions. By preconceptions I mean ideas that students generate independently of school learning, while incorrect or unorthodox knowledge constructed during formal learning will be called misconceptions.

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CHARACTERISTICS OF PHYSICS TEXTS

It is important to consider physics text books because they are used, not only by teachers and students of physics, but also by teachers of other disciplines in order to find out what physics their students might be expected to learn. I should make it clear from the start that I am considering good university and college level texts, written by experts in the subject matter and produced by reputable publishers - the kind of book that is well tried, widely used and respected in university circles. I am aware that there are many rubbishy science texts, especially among those intended for junior school science and young readers. Those books will be treated with the inattention that they deserve, but if you would like to find out something about the bad science that they purvey you could read the useful regular articles by Mario Iona in The Physics Teacher (for example Iona, 1993).

It is also worth noting that some of the features of traditional physics and orthodox texts that I will be challenging are starting to change and I will include examples of improvements that some authors have already adopted. Writers and publishers are now making their texts much more attractive and they are introducing many examples which appear to be related to the real world. It is not my intention to denigrate individual texts but to suggest ways in which even better texts might be produced in future.

Both teachers and students regard text books as authorities. Although even the best texts contain errors, we regard them as less error-prone than ourselves; when they are wrong it is just a problem of misprints or an unfortunate choice of words here or there. On the whole we tend to accept what the books say about the formal knowledge in the subject. It is not my purpose to challenge the validity of that knowledge, but to show that it can be restructured and expressed in different ways in order to make it more accessible and intelligible to naive students.

One of the key roles of a text is to define the logical structure of its subject. That structure is often implied by teaching sequences and the organisation of texts. That there is a commonly accepted logical structure in physics is reflected in the tables of contents of many widely used texts. They are practically the same! Although they have been modernised in their presentation and literary style, modern texts use the same structure as the books of 50 or 60 years ago. They all cover much the same ground, they are organised the same way, and they all adopt similar views about the nature and structure of physics. The tables of contents show that Physics is divided into large segments with names like mechanics, electromagnetism and optics. Within each division there is a predictable sequence of chapters, kinematics before dynamics, force before energy, rotational dynamics after translational dynamics and so on. Such a circumstance could be a sign that physics is a mature subject, but the physics that physicists do is changing rapidly; so it is only text-book physics that is mature.

The uniformity of texts leads to what I regard as a profound misconception about science and physics in particular: that scientific knowledge is definite, unalterable and not to be debated. How can this uniformity be explained? Contrary to the idea that individuals construct their own knowledge, it seems that physics has a hierarchy of knowledge that is fixed independently of the tastes of any text writer. I wish to draw attention to three related features of this hierarchy: basic principles, definitions and complexity of examples.

A common feature of the texts is that they all develop the subject by building on simple basic principles, such as Newton’s laws of motion. Only after a fairly exhaustive treatment of the meaning and application of

Newton's laws is the student introduced to the principle of conservation of momentum which can be derived from the basic laws. In that respect the texts mirror the historical development of physics.

Text books in all subjects seem to promote the learning of definitions. It is certainly part of the culture of physics to define concepts. Starting with a few basic undefined or operationally defined ideas (like mass, length and time) we build up a hierarchy of mathematically derived concepts (like work and energy). Students are thus encouraged to believe that learning definitions is important. This approach is related to a culture of learning that seems to be fostered in Australian schools. When we ask first year university students to write an explanation of an idea, the answer is nearly always a one-liner, in the style of a definition. Although text writers attempt to foster the idea that one can find knowledge and understanding beyond definitions, the definitive approach remains central to orthodox physics. The structure of most traditional texts does not reflect the view that understanding of concepts grows through the experience of using them in many different contexts. To give them due credit, many recent and recently revised texts contain many more illustrative examples than their predecessors, but the examples are still placed firmly in the traditional sequential structure.

Parallel with the notion of building up from basic principles is the tradition of dealing with simple idealised examples before one gets to the more interesting real-world examples. Indeed many texts never get to the real world, especially in mechanics. I will return to this topic later.

Most physics texts do not admit that the knowledge they purvey is tentative or that their theories are not truth but models. One well known text has recently introduced, in chapter 1 of its eighth edition (but not the seventh) about one page on the topic of models, but as far as I can tell the idea is not mentioned again in about 1300 pages. That could leave students with the impression that the theories described are supposed to be some kind of natural truth rather than the models that they really are. Because the texts are so authoritative in their approach, students can develop the misconception that models are facts and explanations are truth. A related omission is the lack of any serious discussion about differences in interpretation of physics. Just as the laws and equations are universal, so, it would appear, are the interpretations that we should make of them. This does not fit well with the research into young people's understanding of science that has revealed a rich variety of modes of thinking about how the world operates.

SOURCES OF MISCONCEPTIONS - THE LANGUAGE OF PHYSICS

There is a common view that the language of physics is mathematics, with an implication that truth lies in the mathematical equations and that explanations in ordinary languages such as English are not the real stuff. The power of mathematical expression is that information is highly condensed and a person who understands the language can extract a lot from a few symbols. That much is well known, but it is not so widely recognised that this kind of coding carries over into Physics English. Physicists like to be economical with words.

One aspect of this Physics-Speak is the substitution of attributes for the names of things. Consider this example which might appear in a physics exam: “a mass is pulled by a light string across a plane surface”. The sled or whatever it is that is being pulled has been replaced in the physicist’s mind by its abstracted property of mass, and the road becomes an abstract plane. Fortunately many of the newer texts are avoiding that extreme kind of shorthand language but they still reflect the physicist’s propensity to transform and idealise the world. I suggest that such abstractions can become misconceptions in the minds of students. Although the physicist is aware of the distinction between a concrete sled and its attribute of mass, that distinction becomes blurred to the student.

Most teachers of physics will agree that the names we use for ideas, being the same as ordinary words, are potential sources of confusion. A widely quoted example is the concept of work. Teachers often use an example of a person holding a brick motionless; students think that this involves work, but the text defines work only if some something is moving. Physics has also hijacked other common words such as force, power and heat, and given them new meanings. Although that is a problem which can clearly lead to misconceptions, there is a related source of difficulty in the use of names within physics.

A well known example of inappropriate naming is a situation, which must have appeared in hundreds of texts, of a book at rest on a table. In older texts you will find that there are two forces on the book, one vertically down called gravity or weight and another vertically up called normal reaction. These forces are said to be equal and opposite, so that the book does not move. In the same chapter of the book you may find a statement of Newton’s third law which proclaims that to every action there is an equal and opposite reaction. Leaving aside the problem of the Physics-Speak oxymoron “equal and opposite”, students can be expected to conclude that the upward force on the book is the reaction to the force of gravity, as described by the third law. That conclusion is a misconception and a serious block to further understanding. One trigger for the misconception is the totally inappropriate name “normal reaction”. (There is another trigger in that the example is too simple, but I will return to that aspect later.) The name is inappropriate because every force is a reaction to some other force; so “reaction” is quite useless as a label for a particular kind of force. Fortunately most recent books avoid the label and give the upward force a more descriptive name such as contact force. I find however that the old terminology is still so widely used by students that it cannot be something that they invented themselves; it must be a learned misconception based on teaching from books. (I think that the origin of this bad naming can be traced to various nineteenth and early twentieth century books whose authors actually suffered from the misconception that the book-on-table example illustrates Newton’s third law.)

Other examples of poor but traditional naming include the following.

- The term tension, which is a way of describing the internal state of an object such as an elevator cable, is used a name for the force exerted by the cable on the lift. Thus a force acting *on* a body is described as the tension *in* something else. The grammatical confusion between “on” and “in” should alert an intelligent reader to a problem with that locution. The confusion arises because it is sometimes useful make the approximation that some kind of average value of tension can be equated with the magnitude of a force exerted by the cable. But instead of learning the reasoning involved, students are encouraged to learn two misconceptions. The first is that tension (a scalar quantity) is the same thing as force (a vector quantity). The second misconception is that tension in a cable can be described by a single value, when in fact it must vary from place to place within the cable. An implicit idealisation has been made. Arnold Arons (1990, pp 74-75), in his excellent book on physics teaching has considered the conceptual problems associated with tension, but has not addressed the issue of names.
- *Acceleration due to gravity* is used as synonym for something which is clearly not an acceleration, *gravitational field*. The confusion is compounded by using the acceleration unit $m.s^{-2}$ rather than the more appropriate unit for field, $N.kg^{-1}$. This common usage produces the widespread misconception, which shows up in student writing, that objects which remain at rest (like the book on the table) nevertheless have an acceleration of 9.8 $m.s^{-2}$.

Those two examples of poor naming can also be seen as a failure to distinguish between related but distinct concepts. One word, and sometimes one mathematical symbol, often has to represent many different shades of meaning. Distinctions between different aspects of the same thing become muddied in texts - and presumably in students' minds.

Although there is a widespread view that the language of physics is too complex, that it contains too many specialist terms, I wish to suggest that one reason that physics is seen as difficult is that it does not have a rich but unambiguous terminology that copes well with shades of meaning.

The single word force, for example, covers for all of the following, among many others:

- the generic idea of an interaction between bodies,
- a class of interactions such as gravity or electromagnetism,
- a particular instance of an interaction,
- a generic vector quantity that is one half of an interaction - force on a body exerted by another body,
- an instance of that generic vector quantity - a particular force on a particular body,
- the magnitude of that force,
- the vector component of that force in some specified direction,
- the scalar component corresponding to that vector component,
- an instance of the vector sum of all the forces on a body.

Experienced readers can disentangle those meanings from context, but I have never seen a text book which enumerates and discusses the possible meanings in a way that is accessible to students. We are equipped to express the shades of meaning only by using clumsy locutions like those in the list above.

Like words, some symbols have to do a multitude of duties. For example the symbol $\boldsymbol{F}$ is commonly used to represent a single force or a total force. Fortunately some authors are now adopting $\Sigma\boldsymbol{F}$ for total force. And many books develop a symbolic notation to distinguish vectors (e.g. $\boldsymbol{F}$), magnitudes of vectors (F) and scalar components (F_x). Unfortunately, even the best texts often drop their own useful conventions once they have explained them in an early chapter. To take one example, the symbol p, which ought to mean magnitude of momentum, is commonly used to represent a scalar component of momentum. The reader is expected to use the context to arrive at the correct shade of meaning.

I have explained the origin of the confusion between tension in a lift cable with the force exerted by the cable on the lift as a confusion between the name of an entity and its value. The equality of values has led sloppy writers of the past to transfer the name of one entity to another so that the inappropriate name has entered the canonical language. That explanation is an instance of another way in which the standard language fails to cope with important distinctions of meaning. The verb “is” gets confused with the verb “equals” and the sign “=” - another widespread misconception which is not difficult for students to correct if it is pointed out. Show them for example a dollar belonging to you and a dollar belonging to them and ask whether they agree with either of the propositions “your money is my money” or “your money equals my money”. Arons (1990) and several other authors have discussed even more shades of meaning in the equality sign, but few texts have yet taken much notice, except for the odd reference in an introductory chapter which is subsequently ignored.

The problems with Physics-Speak are relatively easy to identify. The challenge is to develop a new expanded terminology that will be acceptable to the physics community. That task will have to be done by physicists of some standing who can persuade their colleagues that developing a language specifically to meet educational needs is worthwhile. My own view is that such a project could also improve the standard of communication between physicists.

MISCONCEPTIONS FROM SPECIAL CASES AND IDEALISED MODELS

The text that we currently use in our first year physics course at Sydney University says in its introduction to the first chapter on dynamics: “All of the principles of dynamics can be wrapped up in a neat package containing three statements called Newton’s laws of motion.” Physics as presented in texts is hierarchical and reductionist; it is built on fundamental principles which provide the key to the understanding of all things. The subject is also organised into well defined traditional categories: mechanics, thermodynamics, quantum mechanics, field theory and the like. Although physicists understand and use unifying principles such as conservation of energy, they do not usually organise texts around those principles.

Not only do most texts use the same structure, they develop the subject by building on simple basic principles, dealing with “simple” restricted situations first and gradually building up to more general applications. These canonical texts seem to embody the view that students will not be able to understand real, perhaps complex, examples unless they have a thorough understanding of abstract “basics”. This hierarchical structure can, I believe, cause some conceptual problems for students.

There are two aspects of the hierarchical organisation of knowledge that are worth looking at. Firstly, a lot of physics is learned through simplistic examples which are intended to make progress easy by focussing on one idea at a time. In my view they can have the opposite effect; they can hinder progress because new ideas are not integrated with other knowledge. Secondly, the progression from basic principles to derived principles requires the invention of models which are so idealised that they become detached from the real world.

Take the case of the simplistic examples first. Much worse than the problems caused by inappropriate names is, I think, confusion caused when students learn these simple examples too well. When they come to more general or complex situations they recall the knowledge that they constructed from the simple examples and try to apply it to new situations where it is inappropriate. I would class that restricted knowledge as misconceptions.

Let us return to the example of the book on a table. Even if we avoid the problem of bad naming by not using the name reaction for the upward force, students are still asked to consider a situation in which two forces are said to be “equal and opposite”. Since Newton’s third law also talks about equal and opposite forces, students naturally see the example as an illustration of the third law - even though it is not. Although a text or a teacher may have intended the example as an illustration of the first or second law, that does not help since we know that students construct their own meanings.

Another consequence of the same example is that many students conclude that whenever one object is on top of another one, the upward contact force is always equal to the top object’s weight. This view is reinforced by many more examples in which one always equates the two forces. Students construct, from repeated instances of similar examples, what amounts to a new principle. That principle happens to be wrong, so I call it a misconception. (In a world with air and buoyancy, the new principle is never true, not even when the objects are at rest.)

The other difficulty with simplistic examples is that they do not relate well to real or interesting situations. Consider the problem of understanding force, a favourite topic for research into misconceptions. The orthodox text book tries to explain force using examples with inanimate objects, often starting with objects in equilibrium, such as the book on the table. On the other hand, research has shown that children’s science focuses on active agents and in many cases associates the notion of force with purpose. (See, for example, Osborne and Freyberg, 1985, chap. 4.) Ordinary people understand that things move because we make them move whereas orthodox physics explains things in terms of mysterious abstract forces.

The examples commonly used in physics texts do not relate to the same kinds of situations that students have used to construct their own knowledge about the mechanical universe. If that mismatch is to be remedied then physics texts have to find some new kinds of example. Consider for example how a partially reconstructed physics text might explain the motion of a car in terms of forces and Newton's laws. In particular think about a car going uphill and getting faster as it goes. Since the engine is part of the car it cannot be exerting an external force on the car and it does not appear in the explanation or the equation of motion. (I will return to that little mystery about the engine later.) Standard physics says that the car accelerates uphill because the road exerts a frictional force on it. This conclusion directly contradicts the common misconception that friction always opposes motion. But it may be too late; if previous learning has been based on examples of rigid bodies with no moving parts then students may have already generated the knowledge that friction always opposes motion - even if the text or teacher had never said so. (Actually quite a lot of school texts do say so.) Learning based on a study of rigid objects will never uncover examples like this where friction creates motion.

Another common idealisation is the way we do mechanics in a world without air - because we have some chance of writing the equations of motion in a form that can be solved analytically. Students are asked to accept that neglecting the effects of air is a sensible and natural thing to do. The standard rubric of physics problems, “neglecting air resistance”, can become the misconception that the laws of dynamics are valid only in an airless world.

Probably the main reason for using simplistic or idealised examples is that they are mathematically tractable. If we were to consider more realistic examples the equations would be a lot nastier and we probably would not be able to solve them. Even if the ability to solve equations were important (which is not necessarily true for introductory courses) the old excuse is no longer valid. It is now quite practicable to solve realistic problems using numerical methods with computers. There are also many real and interesting problems which can be formulated, discussed and solved using graphical techniques, many of which correspond to the numerical techniques used in the computers. Although a number of texts now include some acknowledgment of the power of computational physics, the fundamental restructuring of physics knowledge that the new techniques allow has not yet appeared in popular texts.

To summarise, there are at least two difficulties with idealised models. One is that they may not be connected, in the students' minds, with the real world. To a physicist they may be keys to understanding, but a student may see them as unreal make-believe. If that is so there will be no cause for conflict between students' conceptions of the world and the rules of physics, because they are unrelated. The preconceptions and misconceptions remain intact and unchallenged; the student thinks "end of problem, no worries". On the other hand students may perceive that physics is intended as a description of the world. In that case there will be a conflict between their experience of reality and the orthodoxy of physics. The models probably do not answer obvious questions that students may want to ask (such as what makes a car go faster, or where do forces come from). Should they reject the model or their experience? What would we expect them to do?

Not only are text-book examples often removed from reality, the whole theory is presented in a way that is stripped of its connections to the real world. Once again we can find an example in mechanics. The standard treatments generally make no attempt to explain what creates or causes forces; it is simply asserted that they exist. A student might be expected to want to know why they exist and why they seem to take arbitrary values. In fact if one uses models in which real objects are transformed into particles or rigid bodies, then the origin and variation of contact forces cannot be explained. The models which offer the explanations are not presented because the students are not supposed to be up to that yet. The central problem here is that the whole world, not just the examples, has been idealised too much. Although it may be acknowledged that a particle is an abstraction, it is rarely emphasised that in reality there is no such thing as a rigid body.

DIFFICULTIES WITH HIERARCHICAL KNOWLEDGE STRUCTURES

The use of idealised models and examples is related to the hierarchical structure of physics. Let us return to the example of the car accelerating uphill. Ordinary people know that the car's motion is caused by the engine but the physics text talks about external forces on the car, without reference to the engine! A physicist can explain how, through a complex system of internal forces, the engine causes the car's wheels to push back on the road to make the road push forward on the car, but the engine still does not seem to be very important and there is no mention of fuel. A sensible way to talk about the car would be to use the concept of energy, to explain how burning the fuel transfers energy to the car's motion, but you cannot do that if you have to wait until you get to Chapter 8 before you are allowed to say "energy". Students are supposed to develop their conception of force before they are ready for the energy concept. A better approach might be to introduce concepts like force and energy very early, and use them together in many different contexts.

I will give two more examples of the how the hierarchical structure of physics knowledge can encourage misconceptions - from kinematics and relativity.

There has been a good deal of attention paid to studying and improving students' concepts of one-dimensional kinematics (see for example McDermott, Rosenquist and van Zee, 1987). Most of those studies seem to accept the standard text-book approach that an understanding of one-dimensional motion should precede the more general study of motion in three dimensions. That approach can have some unfortunate consequences. For example while studying the one-dimensional case students learn that velocities and accelerations can have positive or negative values. They have also heard that those quantities are vectors, so they naturally associate the positive and negative values with the vector nature of the concepts. The trouble is that the concepts of positive and negative values are not really applicable to vectors. The values of vector quantities can be described in terms of magnitude (which is never negative) and direction, which is an alternative to the concept of sign. To speak of a negative acceleration or a positive velocity is meaningless, but students are actually taught to think in those terms through the study of one-dimensional cases. So by studying one-dimensional kinematics as a separate topic students construct the misconception of a signed vector.

Some fairly obvious examples of knowledge that has to be unlearned come from relativity. In a traditional sequence of physics teaching students pick up the idea that there is something absolute about energy - one cannot create it or destroy it. However there is an important qualification: the amount of energy that a system has depends on your frame of reference. Consider the formula for kinetic energy, $\frac{1}{2}mv^2$, in which v represents a body's speed. Speed is not an absolute quantity; it depends on where one measures it from. So it is a misconception to say that the energy of an object is a property of the object itself, independent of the person who knows it or measures it. Only when a student finally arrives at the chapter on relativity does the difficulty surface. Such misconceptions could be avoided if texts introduced the idea of frames of reference right at the beginning. The change required is not very large - most texts already discuss the question of relative velocity.

OTHER DIFFICULTIES WITH STANDARD TEXTS

Another way in which texts create unintended misconceptions is more subtle than those discussed so far. By implication the texts have reconstructed the historical development of the subject. Generally that is a good thing; while to follow all the old paths and the misconceptions of our predecessors would be a bad thing. But there are some subtle implications in the currently fashionable structure that may hinder understanding. Consider mechanics again.

Some books dodge the issue of cause and effect in mechanics, but those who do take it up usually say that forces cause acceleration and they have many examples to illustrate that point. They set up a problem where enough is known about all the forces so that one can calculate the acceleration. The implication is that the study of mechanics is about knowing all the forces so that you can predict motion. In real science one studies the motion of a body and applies Newton’s laws to find out what the forces are - just the opposite of the text-book approach! If teaching mirrored real science students might discover that some forces depend on speed and that to keep an object moving something has to keep pushing or pulling - which is much closer to their naive conceptions than the idealised world of the current orthodoxy. Explanations of how forces arise would include interactions between solid objects and fluids and the way that contact forces between solid objects arise when the objects are distorted - an explanation that is totally incomprehensible if one believes in the mythical rigid body of conventional teaching.

A final point may bear more on teaching and assessment programs than its does on texts. One of the conclusions that comes from research on learning in physics is that many students are quite adept at solving the traditional physics problems but are weak in qualitative reasoning. That raises the question: do we really need all those quantitative problems? Students’ misconceptions, almost by definition, are related to qualitative concepts but concentration on mathematical formulation may allow students to overlook their conceptual problems. If we do not challenge students to use qualitative concepts we should not be surprised if they construct concepts of their own that do not match the orthodox physicist’s view.

RESTRUCTURING KNOWLEDGE TO OVERCOME MISCONCEPTIONS

Introductory physics needs to be rewritten from a more realistic qualitative perspective. Aspects of reality that get left out of the traditional treatment because they are mathematically intractable can then be brought back. I believe that when this has been done the apparent gap between students' naive preconceptions and real science will be less noticeable and much less problematical.

Students should be given much more opportunity to differentiate among subtly different concepts by studying real examples rather than artificially constructed make-believe worlds. I suggest that if students are given interesting and real examples that they can relate to, they should have a much better chance of avoiding the common misconceptions that arise out of current physics teaching.

What will the reconstructed physics text look like? While acknowledging the power of reductionist models, its approach is holistic. Key concepts are introduced early, even though they may not be well-defined, and they are used often in many different contexts. Using ideas in context replaces the need for neat one-line definitions that can be memorised. The text shows how concepts acquire meaning by using them in many different contexts.

The authors choose their terminology very carefully, avoiding potentially misleading or confusing terms such as centripetal force and acceleration due to gravity. They may introduce some new terms designed to encompass the rich variety of meanings that go with some of the undifferentiated concept-words, like force, that we use now. Once introduced, special terms and symbols are used rigorously thereafter. If it is necessary to define a term, it is never redefined in an incompatible way later.

The text emphasises the idea that scientific knowledge is inherently tentative. The nature, use and limitations of models are explored and explained. The book also explicitly discusses the common naive conceptions and alternative frameworks that have been revealed by educational research. Those alternative views are treated seriously - not dismissively - but their scientific validity is evaluated.

Examples and problems come from the real world, including the other sciences; they are never formulated in abstract terms. Although the examples themselves are never over-simplified, idealised models may be applied to them. The nature and purposes of those idealisations are explained and justified. Special cases are avoided unless they are intrinsically important, and when they are included, they are considered after the more general examples, so that students are not directed towards the learning of incomplete knowledge.

Many of the examples and homework problems are purely qualitative. Both qualitative and quantitative problems include a variety that can be tackled using different approaches, enabling students to see that there is often no unique correct answer to a question. Problem-solving examples are context-rich; they include redundant information and they often require students to supply or seek out factual information. (See for example Heller and Hollabaugh, 1992.)

Finally, our ideal texts will retain all the good features of the best existing books. They will be accurate, attractively presented and well written. The authors will be people who understand their subject and are enthusiastic about communicating that understanding.

There are some practical problems to be solved before such texts become available. Who will write them? I think that it must be done by physicists, not only to get the physics community on side, but to ensure that the new approaches fit well with the real contemporary physics that does not yet feature in introductory texts. Also, I wonder who will publish for us. Commercial publishers will respond to demand, so physics teachers need to be asking for books with new approaches.

CONCLUSIONS

Physics has a reputation for being difficult to understand. I have tried to show here that the reputation may be partially deserved, but it can be improved. Part of our problem has been that physics seems to be about a make-believe world in which things behave differently from the real world. Would it not be appropriate for students to say that, judged on the evidence of the text books, physicists have some severe misconceptions? Perhaps we should go part of the way to closing the gap between them and us by changing physics rather than just trying to change the students.

However changing the physics books is not enough. We will also have to change our assessment practices. As long as it remains possible to pass physics exams by mindlessly solving quantitative problems which have just the right amount of data, I do not see much hope for narrowing the gap between students' conceptions and physicists' conceptions. But that is another story.

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REFERENCES

Arons, A. B. *A Guide to Introductory Physics Teaching*. New York, John Wiley & Sons, 1990.

Heller, P., & Hollabaugh, M. *Teaching problem solving through cooperative grouping; Part 2: Designing problems and structuring groups*. American Journal of Physics, 1992, **60**, 627-636.

Iona, M. *Would you believe? Science Horizons*. The Physics Teacher, 1993, **31**, 168-169.

McDermott, L. C., Rosenquist, M. L. , & van Zee, E. H. *Student difficulties in connecting graphs and physics: Examples from kinematics*. American Journal of Physics, 1987, **55**, 503-513.

Osborne, R., & Freyberg P. *Learning in Science*. Auckland, Heinemann, 1985.