The Role of Textbooks in Physics Learning and Teaching: Current Problems and Future Solutions*

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Physics education research (PER) over the past quarter of a century has greatly enriched our understanding of what works and what doesn't in physics teaching. At a broad range of institutions, from high schools to leading universities, these new insights have been transforming the nature of physics teaching. But physics textbook authors and publishers have to date responded only minimally to the outcomes and implications of this research. In general, textbooks still do not deal adequately with the conceptual difficulties that students have. Moreover, while research has shown convincingly that active engagement is a critical element of learning for most students, those students encounter textbooks as passive learning environments. Meanwhile, there are still many physics educators who cling to methodologies that have always worked well for small numbers of learners but are ill suited to the more diverse body of students they now teach, students who typically were excluded from physics by the traditional approaches. Many of these educators are open to fresh approaches, but lack a textbook that would support such a shift.

The constraints on textbook publishers have been conceptual, technological, and economic and political.

- *Conceptual*: A quarter of as century ago, it was still widely believed that students were well-served by the textbooks being published, and perhaps there was a self-propagating core of individuals for whom that was true – some of them are now senior faculty members who retain these beliefs. Almost three decades of physics education research (PER) have shown that for the vast majority of students who take physics courses, this belief is not substantiated by the evidence. Major textbook publishers now seem keenly aware of the impact that PER has had and can have on physics teaching.
- *Technological*: Until quite recently, textbook publishers were bound by what could be communicated on the printed page. Space was limited; imagery was static; possibilities for interactivity were severely limited. Electronic media have drastically changed this situation. Textbook publishers see a trend towards increasing reliance on electronic media. Although there remains a concern about the extent to which students have access to the technology. this is a circumstance

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in which pedagogical value for the student and economic benefit to the publisher go hand in hand.

• *Economic and political*: A major impediment to change remains. In the United States, book sales are largely dependent on the orders of large university physics departments that service large numbers of students. In such departments, textbook selection is generally a group decision, and is often constrained by the most conservative or traditional faculty members. Publishers are consequently cautious out of fear of losing the support of this group.

The current publishing environment, then, both supports and constrains the development of a new generation of physics textbooks that can better serve the needs of our students.

Encouraged by the support but cognizant of the constraints, I am currently developing a textbook for the algebra-and-trigonometry based (non-calculus) introductory physics course that attempts to address many of the cognitive issues raised by PER. A major goal of this project is to turn the textbook into a more active learning environment, in large part by using electronic media to make interactive material an integral part of the textbook. It is likely that this material will be available to students on a subscription Web site. I have developed all the storyboards for this material, and the programming process has now begun. As a student now turns to a static figure on a textbook page, he or she will be able to turn to a "Weblink" that develops a concept more fully taking advantage of the capabilities of electronic media for animation and interactivity. In addition, many of the in-chapter examples will be on the Web in interactive format rather than on the printed page, so that students can participate in the solution process. In these materials, particular emphasis is placed on the importance of qualitative reasoning in quantitative problem solving. Various examples of the Web-based materials will be presented.

The design of the electronic media pieces and the ways in which they are used are guided by understandings about student learning drawn from PER. For example:

• We know that there is often a gap between students' conceptions of the physical world and the conceptions afforded by systematic application of physics concepts. John Clement popularized the idea of "bridging analogies", situations that provide conceptual stepping-stones from students' conceptions to physics conceptions. In a more general way, it is possible to develop situations that provide conceptual stepping-stones between the concrete world with which students are more familiar and the more abstract formulations of physics.

• We also know from a considerable body of work on novice-expert differences that a beginning student's store of physics knowledge tends to be sparse and poorly interconnected. For them, there is little or no narrative coherence in a physics course, and there is often inadequate motivation for the introduction of new concepts. Most of them need a "story line" to scaffold the connectedness that physicists take for granted. Moreover, the representations that physicists take to be mutually reinforcing windows on the same reality are not always clearly connected for the beginning student.

The textbook I am developing attempts to bring narrative coherence to two–dimensional kinematics by introducing the following story line: More complicated motions can be obtained by combining simpler motions. In particular, two–dimensional motions can be obtained by combining two one-dimensional motions, and can therefore always be broken down into component one-dimensional motions. Vectors are introduced as a mathematical method for accomplishing this.

The story line is advanced by Weblinks that connect these ideas with concrete or easily visualizable situations. Students look at a carnival game in which one uses a hammer to make a weight ascend a wire and ring a bell. The motion of the weight is purely vertical. The game is then set up on the back of a flatbed truck moving at constant speed – a purely horizontal motion. The two motions are combined, and if the weight is illuminated at night, the student sees only the weight's composite motion, which is indistinguishable from projectile motion. As the synthesis of a motion from two component motions can be made concrete, the analysis of projectile motion into component motions can be made more concrete by viewing the motions of the idealized shadows, say, that the projectile casts on a wall and the ground. The Weblink permits the student to look concurrently at the actual motion, the shadow motions, and the changes in the vectors representing the positions of the shadows, in order to reinforce the connectedness among these representations. It also leads to a pictorial way of understanding why there must be a radial force on an object traveling in a circle at constant speed.

The book introduces Weblinks – typically three or four per chapter – for all content areas. In Weblinks relating to wave motion, the spacing of doughnuts on a conveyor belt is used to explore the spacing of crests in the Doppler effect, and the behavior of a wheel constrained to move vertically as a wooden waveform is pulled along under it is used to give conceptual meaning to $v = f\lambda$, which too often students simply memorize. In that these bridging situations mediate between the concrete and the abstract, I like to think of them as *concretions*.

Some Weblinks specifically target common conceptual difficulties. For example, students often confuse the conceptually distinct circumstances in which equal and opposite forces occur – the equal and opposite forces that sometimes are exerted on the same object that produce equilibrium, and the equal and opposite forces that two objects always exert on each other. A Weblink addresses this difficulty by exploring how the gravitational forces exerted on and by a rocket change as the rocket passes through the point where it is pulled equally by the Earth and the Moon. The same difficulties are addressed in a Web Example – an in-chapter example presented electronically -- in which a person on an icy surface pushes a crate which in turn pushes a second crate.

Both the Weblinks and the Web Examples ask questions of the student as the narrative proceeds, and also follow-up questions. It is hoped that enough of these will be assigned by the instructor to insure that students will be turning on a regular basis to the electronic media material and using it as an integral part of the text. It is also hoped that by recording students' responses and making them available to the instructor, the instructor who wishes to do so either for research purposes or for formative evaluation can obtain a detailed picture of what the students do or do not understand.

The Weblinks also serve the purpose of breaking out of two major constraints of printed page textbooks – the fact that space is limited and the fact that the printed page is static. A diagram with many parts and with several concepts involved can be hopelessly confusing to the beginning student. Electronic media allow us to introduce the elements of a diagram one at a time and likewise to engage the student in addressing the relevant physics concepts one at a time. Quite simply, the medium can be used to direct the student's attention in a way that the printed page cannot. To the extent that time permits, Weblinks on the mass spectrometer and the photoelectric effect will be presented as examples.

As stated earlier, presenting the in-chapter examples electronically in interactive format rather than on the printed page permits students to participate in the solution process. Emphasis is placed on the importance of qualitative reasoning in quantitative problem solving. Students are frequently asked to identify which concepts are relevant to the solution of the given problem, or what conditions are applicable. (There is evidence from PER that students who tend to do this tend to be better problem solvers.) Examples dealing with simple electric circuits will be presented.

In the textbook itself, qualitative and quantitative end-of-chapter problems are not listed separately. Indeed, problems often have both qualitative and quantitative parts, to reinforce the perspective that qualitative and quantitative reasoning are not ultimately separable. End-of-chapter problems will also be available electronically

The content of the printed text also aims to support the way students learn best. For example, most students have to construct abstract ideas as extrapolations from a prior body of concrete experience. They need to engage in a conceptual exploration of the physical phenomena before mathematical formalisms can have meaning for them. To address these needs,

- an entire chapter on Newton's laws that is primarily qualitative precedes the chapter in which the laws are applied extensively to quantitative problem solving. An entire chapter looking qualitatively at the microscopic models we use to explain electrical phenomena precedes the more quantitative chapters on electricity.
- concrete "cases" – brief discussions of specific situations -- are presented to raise new questions or introduce new approaches or new phenomena before they are discussed in more general terms . For example, a case involving a specific set-up in which students see evidence that magnets exert a force on a wire when a current passes through it precedes and motivates the ideas that are compacted into the information-dense equation $F = qvB \sin \theta$.
- "on-the-spot activities", generally of a kind that students can do without the need for special equipment, are introduced to get students to think actively about the concepts being presented. For example, there is an activity in which students manually simulate the operation of an *xy* recorder, using a pencil and a moving straight edge to produce a trace of the pencil point's resulting two-dimensional motion.

Moreover, as noted earlier, the connections among ideas in a physics course are not self-evident to students. For these students, we need to motivate the approaches that we take, to introduce phenomena and raise questions before offering explanations, to motivate and construct concepts before naming them.

We also need to encourage students to read more actively – that is, to think about the material and raise questions about it as they go. The on-the-spot activities are one device that encourages this; frequent "stop-and-think" questions are another.

Still, the extent to which this or any textbook contributes to an active learning environment will depend critically on how it is used. It will do so only to the extent that the instructor chooses to use it that way, emphasizing and assigning its active-learning components. This will depend substantially on treating the electronic media materials as an integral part of the text. Textbook publishers are expecting that in the future there will be an increasing reliance on materials delivered through electronic media, and a corresponding decrease in printed text materials. In that sense, the project reported here represents a transition state. The hope is that it represents a transition state towards a more supportive learning environment for our students as well.