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## WHITHER/WITHER THE PHYSICS TEXTBOOK IN AN ACTIVE/INTERACTIVE ERA?

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The textbook presently seems to be the core element in the large introductory university physics course, determining the content, pace, and approach taken by the instructor and students. Yet there are a number of trends that seem to portend deep change in how the text is conceived and used. Few instructors are satisfied with the text: "It covers too many topics, it does them in the wrong order, it doesn't do things in the way I like." Few students actually read the text. Research has increasingly demonstrated that "active learning" is much more effective for students than the "transmissionist telling" that seems the model for most texts. And finally, an upcoming generation of students seems much more comfortable with obtaining their information on-line, often with active game-like components and video. In this poster, I explore some ways the text can be adapted to the current university physics learning environment that is increasingly incorporating more active learning elements. I then consider the future and whether web documents with interactivity will lead to the textbook's just "withering away" despite its apparent current vitality.

### **1. Introduction: Both learning and text-delivery environments are changing**

Physics educators have sought sought alternative approaches to the physics text for decades – computer tutors, self-paced instruction, distance learning. Despite this, the introductory college physics textbook is still with us. The textbook of today has not only failed to wither away, it has burgeoned – grown into a costly, overweight, cumbersome, and difficult to use encyclopedia packed with information. An introductory physics text now typically has over 1000 pages, full color pictures, cute drawings, and examples and photos to "make the text relevant to everyday student life." There are dozens of competing texts and even marginally successful ones come out with "new" editions every couple of years. On the surface, this looks like an incredibly successful component of our education system.

Nonetheless, in practice, most students buy the text only because the professor assigns problems (or readings) from it and because it contains collections of data (equations and factoids) that they can use to solve the required problems -- or answer questions on a recall-without-thinking exam. Most students don't value their text and are happy to sell it immediately after the class, and new students are happy to buy a used book at half the price.

In my experience, few students read their textbook as a part of their development of their knowledge of physics, and few keep their text as something of value after they have finished the course. (This is somewhat less true at the more advanced levels, but there is still resistance to reading text.) Despite this, texts still exert a powerful influence on introductory university physics classes, controlling content, pacing, notation, and orientation.

Although the text is still the nominal core of a physics class, in practice, things are beginning to change. As a result of research in physics education at the university level, the delivery of learning environments in physics has been evolving for more than a decade to include a collection of materials that may include a traditional narrative (text) but can expand to include more active-learning components, such as group-activity worksheets, laboratories, and in-lecture interactive demonstrations. The coordination and synchronization of these materials is an important step that we are now struggling with.

In section 2 of this paper, I consider some of the issues in integrating text materials with these newer active-learning environments. As an example, I discuss *The Physics Suite* [1], an

attempt at integration that my colleagues and I in the *Activity-Based Physics Project* [2] are carrying out.

Looking farther ahead, it seems that the web offers possibilities that could dramatically break the lock publishers have on the delivery of text. The multi-tasking graphical user interface of modern computers and the universal web-delivery system offer some powerful opportunities for extending and expanding the delivery of text information: hypertext structuring and linking, and the association of multi-media and text – videos, calculational tools, simulations, etc. In addition, new group authoring tools such as Wikis have s powerful implications for the longer term. I discuss the implications of the web in section 3.

## 2. Research has shown that “active-learning” is more effective than passive and many developers have created effective research-based learning environments.

Researchers in discipline-based physics education research (PER) [3] have been studying specific student difficulties for 25 years. As a result of this research, they have developed a much better understanding of the kinds of challenges physics students encounter. Building on this research-based knowledge, developers have begun creating learning environments through a cycle of research and re-development. (See figure 1.)

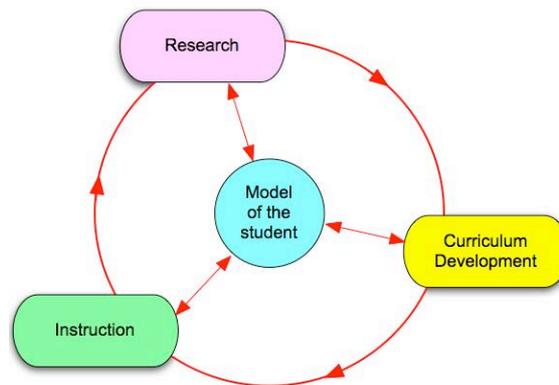


Fig. 1: The research and re-development cycle for the creation of effective, well-tested, and well-documented learning environments.

In discipline-based PER a philosophical and theoretical consensus of curriculum design is beginning to emerge. This consensus is based on a constructivist model of student thinking and learning and a peer/mentor supported active-learning model of the classroom. Some examples of these environments include:

- *Peer Instruction*, conceptual problems for use interactively in large lectures [4]
- *Tutorials in Introductory Physics*, group-learning worksheets for developing conceptual reasoning skills and learning basic physics concepts [5]
- *Workshop Physics*, a full laboratory (no lecture) environment enhanced by powerful computer data acquisition and analysis tools [6]
- *Real-Time Physics*, a concept-building laboratory environment using the computer tools of WP in a more traditional lab setting [7]
- *Interactive Lecture Demonstrations*, a set of worksheet guided lecture demonstrations [8].
- *Tasks Inspired by Physics Education Research (TIPERS)*, a set of research-based homework problems [9].

These and other examples are discussed in *Teaching Physics with the Physics Suite* [10].

Research-based active-learning environments can have a dramatic effect on improving student learning [10][11]. In my experience as a teacher of introductory physics in large lecture courses, I have often found that traditional physics textbooks often

- are largely didactic, giving no epistemological or empirical base for the knowledge given, often introducing terms and equations at the beginning of a chapter that cannot be made sense of without material appearing much later in the chapter
- contain highlights, boxes, and summaries to allow students to select items for memorizing
- contain only problems whose answers can be given as numbers, listed in the back (for the odd-numbered problems)
- ignore what has been learned from PER about student difficulties, giving examples that encourage students' inappropriate associations or interpretations.

These and other such characteristics of traditional textbooks not only fail to support the proven and effective modern environments, they can confuse students, sending meta-messages about the nature of the knowledge to be learned that contradict what the new active-learning environments are trying to do. Once I began adopting active learning environments in my teaching of introductory large-lecture physics classes in the late 1990's, I began to stop requiring my students purchase a text, and indeed, I began to discourage them from doing so.

### ***2.1. How can a textbook be made to complement active-learning environments?***

#### ***Example: Understanding Physics and The Physics Suite***

In the late 1990's, my colleagues in the *Activity-Based Physics Project* and I [2] decided to explore whether the traditional physics textbook could be coordinated with the new active-learning environments. We conceived *The Physics Suite* – an environment that would integrate a variety of active-learning environments with a transformed text.

In our conception of this project, the textbook was demoted from the central element of the class to one tool among many that could be offered to the students. At the center of our vision was a philosophy and pedagogical approach as explained and discussed in the teacher's guide to the Suite [10]. The elements of the Physics Suite are displayed in figure 2.

In order to carry out this project, John Wiley and Sons gave us permission to modify one of their popular textbooks [12]. To coordinate the narrative (“textbook”) with the other elements of the Suite, we made lots of changes (so many that they gave us a new title and authorship) [13]. Some of the changes we made include:

- We matched notation across the many different elements (harder than it sounds!).
- We rewrote didactic elements to motivate and base them in experience and experiment.
- We elaborated issues known to be difficult or confusing for students to take into account what has been learned from PER
- We replaced artist-constructed idealized graphs by real data of the type the students might take (or see taken) in the other elements of the Suite.

This last point is illustrated in figures 3 and 4 below. In figure 3, Newton's 3<sup>rd</sup> law is illustrated by the data taken by two force probes attached to carts of different weights banging into each other. This experiment can be done by the students using the same computer assisted data acquisition equipment in other elements of the Suite – RealTime Physics, Workshop Physics, Activity-Based Physics Tutorials, or Interactive Lecture Demonstrations. In figure 4, the data taken from a video of a walking woman is converted to a graph using *Videopoint*<sup>TM</sup>, a tool for taking data from video clips created for and used in Workshop Physics.

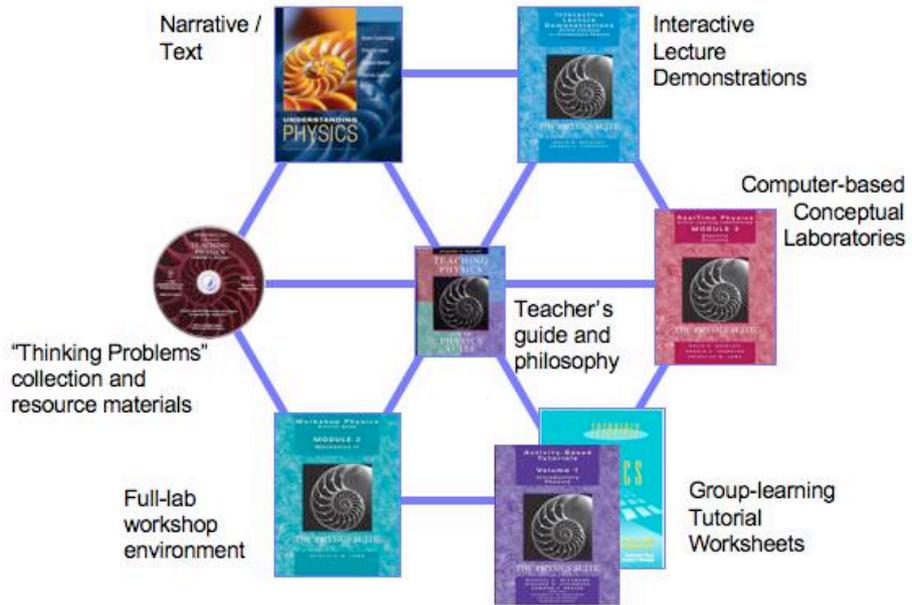


Fig. 2: The elements of *The Physics Suite* [2], created by *The Activity-Based Physics Group*.

**FIGURE 3-28** = A graph of the measured force vs. time for two people playing tug-of-war for 10 seconds. A computer data acquisition system was used to collect and display the data at a rate of 100 readings per second. Force *A* is exerted on the person on the left and force *B* on the person on the right.

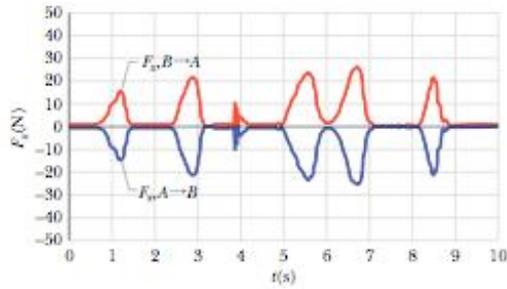
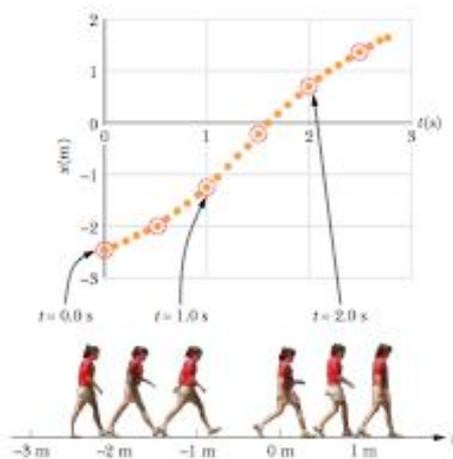


Fig. 3: A figure from *Understanding Physics* showing Newton's third law by displaying the forces read from two force probes attached to carts of differing weights [13].



**FIGURE 2-9** = A graph that represents how the position component, *x*, of the walking student shown in Fig. 2-7 changes over time. The motion diagram, shown below the graph, is associated with the graph at three points in time as indicated by the arrows.

Fig. 4: A figure from *Understanding Physics* showing the mapping of linear motion into a graph of position [13].

## 2.2. How can a textbook become more active-learning oriented?

It's not enough to just transform the text so it doesn't get in the way of active-learning elements in a course. It would be appropriate if the text contained active elements of its own. Some texts are being planned that will be more interactive than the current generation of texts [14], but they will contain more workbook-like components and, at present, it is unclear how either students or faculty will respond to them. Even within the current textbook structure, there are many things that can be done to encourage students to mentally engage with the text.

Here are some of the things we have tried to do in our text for The Physics Suite, *Understanding Physics* [13].

1. *Take an epistemological orientation* – Instead of simply stating results, a text can try to begin where the student is beginning and work through reasoning that takes one to the desired conclusion. This encourages the student to focus on how things are figured out, not just on the results.<sup>1</sup>
2. *Provide well-chosen “stop and think” problems* – Include frequent “reading exercises” that challenge well-known student preconceptions and are good starting points for a class discussion.
3. *Remove the chapter summaries and help students learn to build their own* --- Creating one's own summary is one of the most effective tasks in learning to organize the knowledge one is developing. Giving such summaries severely discourages the student from carrying out this valuable exercise.
4. *Model problem solutions but not algorithmically* -- Teaching students that problems should be approached by rote without sense making is the wrong message. Model solutions should include thinking about problem structure and mechanism, use of basic principles, and evaluation of the plausibility of the result.
5. *Offer a rich variety of problems* – Too often physics texts offer problems that are either too simple (exercises – simply find the equation, manipulate a bit, and plug in numbers to get the answers) or too hard (complex problems requiring a high level of expertise). We include a wide variety, including conceptual questions, essay questions, estimation problems (Fermi questions), representation translation problems, and context rich problems. (See [10, Chapter 4] for a discussion and examples.)

## 2.3. What are some of the barriers to effective text creation?

Despite the presence of dozens of introductory physics texts, all carefully and beautifully prepared as the cost of extensive labor by both authors and publishers, most physics texts are very similar. It would be wonderful to be able to choose from a wider range of possibilities: much shorter and more concise texts, texts that do not cover every topic in massive detail, texts with a more historical or philosophical orientation, texts that vary the order of content dramatically – say starting with optics instead of Newtonian mechanics. Almost no such texts exist (although there is some evidence that variations may be beginning to appear – see [15] for a good example).

Perhaps the greatest impediment to the creation of powerful and integrated active-learning suites is the unwillingness of many faculty to spend the time and effort to understand the results and implications of education research and to go beyond teaching the way they were taught. They largely focus on "What content should I present?" instead of "What skills

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<sup>1</sup> Note that this does not mean take a historical approach. An individual's cognitive learning no more recapitulates scientific history than phylogeny recapitulates ontogeny. Students begin neither with the skills nor the mindsets of ancient scientists.

do I want to help my students learn?" Publishers are driven by the bulk market and tend to drive textbooks to a mediocre sameness, trying to please everyone rather than be willing to take a leadership role and try innovations. When a few faculty at major universities dislike a particular innovation, the publishers exert strong pressures on the authors to return to the norm. The fierce competition for trying to achieve a large market share drives out any text that isn't similar to the most popular one. (For a Darwinian explanation of why this sort of thing happen in competitive situations, see Stephen J. Gould's article on why there are no longer any .400 hitters in baseball in [16].)

A second factor in textbook mediocrity is the short time in the "new edition" cycle. The primary reason that texts go to new editions every few years is to "kill the used textbook market" which would otherwise almost completely eliminate new book sales in three to four years. Publishers of texts competing for market share release new editions in a rigorous three-year cycle. The largest customers typically reconsider new textbooks in the year when their old text goes to a new edition. If you don't get your book out in the year to match the competition, the largest customers will have just switched and be unwilling to consider your variant. Publishers can exert severe pressures on authors to meet this time scale and to produce enough cosmetic changes to justify a new edition. This pressure tends to drive authors away from the more thoughtful and time consuming activity of considering serious or deeper changes.

### **3. Web technology is changing the way we can create text environments and the way people interact with text**

According to Gould [16], the narrowing of variance in a competitive environment is a natural result of mature competition – competitors adapting to a stable environment. Only when the environment changes radically does one observe evolutionary radiations – the dramatic branching of well established species into new forms to take advantage of new ecological niches. Perhaps the creation of web technology is creates sufficiently different "ecological niches" for text distribution that we can hope for some dramatic changes in the form of textbooks in the near future.

I consider three changes highly likely, if not inevitable: the extension of text to include multimedia components, the opening of the text into non-linear forms, and the creation of evolving texts created by groups rather than small numbers of authors. For examples, I will draw on some of the text delivery I am currently experimenting with in my class, "Intermediate Theoretical Methods" (Physics 374) at the University of Maryland

#### ***3.1. Web technology allows the inclusion of multi-media components***

For many years now, people have talked about how computer technology would enable "living texts" – videoclips instead of static pictures, explorable simulations instead of graphs, and complex problems solving tools such as spreadsheets, data acquisition probes, and symbolic manipulators [17]. Textbook publishers tried to jump on this bandwagon, creating CDs with videoclips and simulations supplementing their texts, but these have had little impact in practice. The web allows for a community of individuals to share resources, providing access to a wide range of supplementary tools.

In my Physics 374 class, I provide links to supplementary reading that allow students to go beyond the problems at hand, provide links to webpages that include simulations, and provide downloadable programs that the students can run and modify on their own computers.

### 3.2. Web delivery of text allows non-linear structuring and linking

One of the most exciting ideas in computer-based text delivery is hypertext. The earliest implementations include Ben Shneiderman's Hyperties [18] and Apple Computer's Hypercard for the MacIntosh. Programs such as these allowed linking of text elements and the modes of connecting text they explored form the basis for the now well-familiar world wide web of information.

Although text delivery using the web over the Internet is now common, there has not been much study of how to best structure text materials in order to facilitate the learning of complex topics by novices. For example, the on-line encyclopedia, *Wikipedia* [19], provides the a page of information on Fourier series, a topic I discuss in Physics 374, beginning on the page shown in figure 5.

The screenshot shows the Wikipedia article for "Fourier series". At the top, there are navigation tabs for "article", "discussion", "edit this page", and "history". The article title "Fourier series" is prominently displayed, followed by the text "From Wikipedia, the free encyclopedia". A summary paragraph explains that Fourier series are used for analyzing periodic functions by decomposing them into weighted sums of sinusoidal components, known as normal Fourier modes. It notes that these modes are often easier to work with than the original function. A sidebar on the right lists related topics like "Fourier transforms", "Continuous Fourier transform", "Discrete Fourier transform", and "Discrete-time Fourier transform". The main text includes a "Definition" section and a "General form" section, which contains a mathematical equation: 
$$\int_{-T/2}^{T/2} |f(t)|^2 dt < +\infty,$$
 and mentions the Fourier series expansion of  $f$  about  $t = 0$ . The page also features a search bar, a toolbox with links like "What links here" and "Upload file", and a list of other languages.

Fig. 5: A page from Wikipedia [18] giving information on Fourier series.

The page contains a linear table of contents outline plus every sentence contains links to pages explaining technical terms. This material is encyclopedic (as intended) rather than pedagogical and it takes what appears to be an unplanned approach to linking. That is, the text is written in a linear fashion and then links are added after the fact to any term that has available information on other pages.

An alternative and more educationally oriented approach is to consider where students are and what confusions and difficulties they might have. Even more interesting, perhaps, is to consider the fact that students often don't really have any idea why they are doing what they are doing at any particular point in time; they have trouble getting the "big picture" and putting the bits of knowledge they are struggling with into perspective. The use of linked text might provide visible structures and markers that could help.

In figure 6 below, I show the main elements of a set of text materials I am creating on the web for my Physics 374 class. I plan to use the hierarchical tree structure with progressive disclosure as a table of contents and to use the tree reduced in size with different boxes highlighted as icons at the start of each text element to show which items the text relates to.

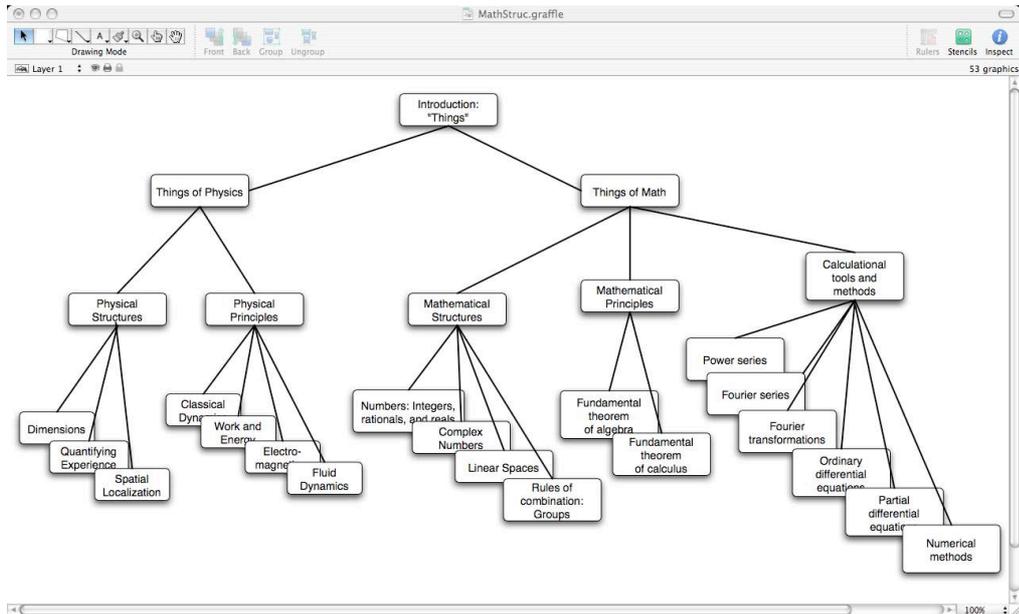


Fig. 6: The structure for the content for a web text in mathematical physics.

A second element one might introduce are iconic markers to identify threads and motifs throughout the material. In my Physics 374, I want students to focus on the issue of thinking both about the physics and the math and weaving their knowledge of the two subjects together. This is often problematical for them: they either use their physics knowledge or their math, often mistaking bizarre errors by cleaving to one side or the other. To focus students on this issue, I have created a diagram that allows us to talk about the components of blending the two subjects together. It is shown in figure 7 with associated icons that will identify the components of various problems and readings available on the class website..

**Structure: Doing Physics with Math**

We use our "4-box diagram": as a guide to the structure of the course. By paying attention to which box we're in or which connection we are talking about, we can be sure that we have not missed thinking about any part of the complex process of applying math to physics.



<p>A.</p>	<p>The Starting Physics: This icon indicates a topic that focuses on selecting what physics to choose to use in describing the system. Learning to "find the physics" in a real world problem is one of the key skills of a good physicist.</p>	<p>1.</p>	<p>Modeling: The step involves mapping the physics we have selected to pay attention to into appropriate mathematics. We have to not only assign symbols to physical quantities, we have to decide what kind of "mathematical things" our symbols stand for.</p>
<p>B.</p>	<p>The Mathematical Structures: Math provides a variety of structures with well-established quantitative relationships that we can use to represent quantities in the physical world. It is important to know a variety of structures that might be used and to well understand their basic assumptions and relations.</p>	<p>2.</p>	<p>Processing: In this step we are "doing the math" - focusing on the solution and/or manipulation of the mathematical equations. We need to know what each mathematical term means so as to be able to take it down to basic definitions when a problem arises.</p>
<p>C.</p>	<p>Mathematical Results: Math structures allow us to process our initial formulation -- perhaps an equation -- into another form -- perhaps a solution -- that we can then interpret in a way we could not when the formulation was in its initial state.</p>	<p>3.</p>	<p>Interpreting: This link tells us to re-interpret our mathematical results in terms of the physics of the original situation. A math solution is not enough. It has to tell us something about the physical system.</p>
<p>D.</p>	<p>The Physical Results: Once we have generated our mathematical results, we need to process it back into physics in order to extract the meaning of the math. The physical system we have created with our math may be a caricature of our original system for a number of reasons</p>	<p>4.</p>	<p>Evaluation: Our final step is to evaluate whether our process brought us to an appropriate place. We have to compare the physical results we get from our modeling, mathematical processing, and physical interpretation with what we know about the system we started from.</p>

Fig. 7: Illustrating the use of iconic markers to place diverse text items into a broader perspective.

These hypertext approaches offer the possibility of getting students to take a longer view and to begin to see the relation among the many elements of the class. Of course there is always the problem that students may get “lost in hyperspace” – a problem identified immediately upon the creation of hyperlinked material in the 1980’s but one often discussed but not yet solved.

### **3.3. Wikipedia allows a community to create a text**

Wikipedia [19] offer more than just an on-line example of hypertext. This on-line non-commercial encyclopedia has the intriguing feature that it is developed by a community rather than by an individual. Anyone can contribute or modify an article. At present, Wikipedia has more than 1,000,000 articles in English and translations of many of those articles into many other languages. This technology would permit a group of interested teachers (perhaps a group of 25-50 authors) to jointly construct an online textbook. Such a collaboration might have a different look from the texts currently created by one, two, or four authors.

This could also help break the cycle-time lock that impedes traditional textbook improvement. Moreover, a Wiki text could be more blog-like, having frequent links to the many excellent simulations and elaborations that are beginning to appear.

## **4. Conclusion**

Technology is changing the pattern of text delivery in many ways, offering many new opportunities not just for delivery of materials but also for restructuring them. But a rapidly changing environment produces dangers as well as opportunities. For example, putting large efforts into developing materials dependent on a particular software or hardware element could result in losing the fruits of those efforts as markets change. What is needed is the development of a deeper understanding not only of what is possible, but what the issues are and what works.

Will the textbook “wither away” to be replaced by active learning components and interactive web delivery? Not today or perhaps even tomorrow, but it is clear that some dramatic changes will happen – and soon.

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