Traditional versus Nontraditional Approaches to Introductory Physics Prove to Be a Textbook Case

I have some negative reactions to Joseph Amato's article, "The Introductory Calculus-Based Physics Textbook" (December 1996, page 46).

Amato states that the introductory physics course should attract students to physics. When demand for physicists is high, perhaps a first-year course might attempt to attract qualified students into the field. When demand is low, however, the course might just as well serve as a filter, selecting out only the very best.

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Physics is a vast field. No one person can master it all. Similarly, I wouldn't think that one single "story line" could possibly organize everything we want to say in a physics survey course, despite what Amato believes Randall Knight has done successfully in *Physics: A Contemporary Perspective*. In fact, six ideas—as in Thomas Moore's *Six Ideas That Shaped Physics*—don't seem enough to me, although they do to Amato. As Einstein said, "Everything should be made as simple as possible, but not simpler."

Priscilla Laws's *Workshop Physics* seems to be an attempt to make physics more experimental and less mathematical. Are we simply running away from math because students don't like it? In general we must remember that a good course is not the same thing as a popular course. I would rather we have students take a few more math courses prior to attempting physics. Also, how would we ever get to the small class sizes required by this approach?

Amato declares that "there has never been a consensus among physics teachers concerning which topics are essential to the introductory course." I disagree; the uniformity of first texts argues against such an assertion.

So what should we do? If students are less prepared then they once were I would suggest that we take three semesters to teach a two-semester course. Under this arrangement, I would credit students with two semesters of work—and credit professors with three semesters of teaching load.

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Joseph Amato's article is only one of a veritable stream of similar complaints about the failures of physics education and their consequence—the small number of students who elect to follow a course in physics.

There is one reason that teachers fail to make physics interesting that is not mentioned in the article. It is this: The attempt over the last 40 years or so to make physics attractive by introducing early what are seen as modern and glamorous subjects has resulted in students failing to fully understand the foundations of the subject. The same is true for other sciences.

My granddaughter, for example, is taking a high school course in elementary chemistry. She has been presented with the periodic table in terms of the electronic structure of atoms, but she has not been taught the properties of elements. Nor has her course covered Dimitri Mendeleyev's achievement in bringing order to a vast corpus of knowledge of chemical reactions, and in developing the means of searching for unknown elements.

Students, even in middle school, are now taught the nuclear atom, yet few have any idea of how we ever came to the conclusion that that is how the atom is configured. I remember how, in 1943, I was intrigued on reading James Arnold Crowther's university-level textbook *Ions, Electrons and Ionizing Radiations*. What excited me was that I could understand how people came to the conclusions, which we now accept uncritically, about the microscopic nature of matter.

Students nowadays are asked to accept and believe in something they cannot see and that has almost no relation to their everyday experience. As physicists, we used to make fun of mathematicians because they would present a subject beginning with a set of axioms. That was the basis of a logical structure that we all understood and appreciated; the only thing missing was an explanation of why they ever thought of those axioms in the first place.

For many first-year university students, the image of physics is not a magnificent and logical structure built on the shoulders of giants, but a set of disjointed facts. For them solving a physics problem often means resorting to the stratagem of matching keywords in the problem to a list of formulas in the textbook. They don't understand the logical basis of the subject because they have not been taught basic concepts.

There is a lot to be said for not running before you can walk, and for presenting science in a well-chosen historical perspective. The result of not doing so is that science is not related to the average student's experience, and only those who already have the enthusiasm will fill in the gaps.

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I read Joseph Amato's article anticipating the rebirth of texts that would be more comprehensive, rather than the symptom of some form of educational anorexia. Although my experiences do not predate Albert Einstein, I remember what many physics departments taught 20 years ago—a three-semester (or four-quarter) sequence that included all of the fundamental topics plus topics that helped to prepare the typical engineering student for his or her engineering courses. Integration of 20th-century physics into the current reduced physics core (now typically only a one-year sequence) has led to a significant reduction in that preparation.

According to Robert C. Hilborn's article "Recognizing the Importance of Undergraduate Science Education" in the February 1997 issue of *APS News*, "Only 3 percent of the students who take calculus-based introductory physics in college go on to take another physics class." Wow! This means that 97% of those who purchase the texts used to teach this material are not going to be physicists. The majority of them are probably engineering students who need to have a firm background in statics, dynamics, thermodynamics, circuits, and electricity and magnetism.

Amato describes some interesting and inventive texts that may raise the level of excitement for the learning of the fundamental premises of physics. Please save these for the general education courses offered to nonphysics and nonengineering majors. But please give us back a physics curriculum that serves engineering students.

Modern physics should certainly be a component of the introductory physics curriculum. It should not, however, replace required competencies in the three-dimensional motion of particles, rigid body dynamics, the fundamental (and historical) character of classical thermodynamics, or the beautiful connection between the electromagnetic properties of particles (namely electrons) through Maxwell's equations, which, in turn, function as luminaries by virtue of their resulting wave equation for light.

What I fear most is that, because of the continued loss of such valuable material from the texts and curricula of physics courses, engineering departments will forsake physics completely and enroll students directly into engineering courses. That would not be a pretty sight from either perspective!

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The excellent review article by Joseph Amato suggests that our introductory textbook *Electric and Magnetic Interactions* would be improved by the addition of material on interference and diffraction. We have in fact written supplementary chapters on physical optics and on confined waves for use in our own course, and we are happy to supply these chapters to teachers who are using our book. For further information, go to the World Wide Web and see http://cil.andrew.cmu.edu/emi.html.

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Joseph Amato's article prompts us to describe an experimental freshman physics course that we are currently testing at New Mexico Tech. The experiment is still in its early stages, but we are excited about the results so far.

In designing the new course, we have drawn on the attempts of others to improve the pedagogy of freshman physics, have retained the convention of taking a systematic approach to the subject and have compensated for the chief deficiency of the traditional course's content—that is, its almost complete neglect of 20th-century physics.

In the traditional course, mechanics appears first in the sequence of subjects because it is generally considered to be the best foundation on which to build the edifice of physics. However, this approach seems to inevitably squeeze all of 20th-century physics into the last few weeks of the course. A close reading of modern physics suggests an alternate possibility: Optics and relativity may actually provide a better foundation for physics than mechanics does. Optics provides an attractive context in which to develop an understanding of diffraction, interference, wavepackets, group velocity etc. Relativity promotes spacetime thinking and is a good antidote to Aristotelian physics.

After the development of optics and relativity, we introduce quantum mechanics by building on the student's newly acquired knowledge of waves and the idea of Lorentz invariance. (The Schrödinger equation is neither needed nor used.) The ideas of energy and momentum are developed in an unconventional but logically defensible fashion. Classical mechanics is treated as the "geometrical optics limit" of quantum mechanics.

At the end of the first semester, the students end up with a mathematically simple, but conceptually nontrivial, acquaintance with relativity and quantum mechanics, the two legs upon which modern physics stands. They have also had the chance to grapple with some of the most exciting and mysterious ideas advanced by modern science and have made a start in understanding classical mechanics. Ample time for such other subjects as electromagnetism and applications of classical mechanics is available in the second semester.

Perhaps the biggest lesson we have learned so far is that optics and relativity may indeed be more effective than mechanics as an entrée into physics for beginning college students. The strong interest in the subject matter shown by the students in the pilot section of this course encourages us to believe that we are on the right track.

We have had to produce extensive course notes for the students, as most of the course material course is not covered satisfactorily in traditional physics texts. This material is available on the World Wide Web in the form of Postscript documents linked to an html backbone: http://www.physics.nmt.edu/raymond/phl2x/phl2x.html.

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Amato replies: The objections raised by Jones, Daniels and Chasnov to nontraditional introductory physics texts and curricula are important and understandable. Their concerns mirror my own immediate reactions to proposed reforms in, say, mathematics or chemistry education.

I was introduced to physics through the use of a traditional text, and I believe it served me well. But readers of PHYSICS TODAY are not typical of the students currently enrolling in our introductory physics classes. Education researchers have demonstrated incontrovertibly that there is often a shocking disparity between what we think we are teaching our students and what they carry away from our classes. Coverage is not the same as learning, and, in the traditional text, physics fundamentals are often drowned out by details. Indeed, it is for precisely this reason—that the traditional approach obscures fundamentals—that these new texts and teaching strategies have been devised.

Furthermore, it is well known by educators from elementary school through college that organizing subject matter around an easily identifiable theme enhances teaching effectiveness by heightening student interest and motivation to learn and by promoting integration of the various course topics. The new texts do that admirably, without sacrificing the treatment of the principles of, say, classical mechanics or electromagnetism.

I do not agree that the introductory course should purposely serve as a "filter," or that it should be a primer for the engineering curriculum. The primer strategy has led to the inexorable swelling of the traditional text and, as reported by education researchers, to the pedagogical decline of the introductory course. The fundamentals of physics are eminently applicable and transferable to the other sciences and engineering, and our mission should be to highlight these principles and make them as understandable and accessible as possible.

I regret that I learned of Sherwood and Chabay's supplemental materials on waves only after my article was in press. In that article, I also criticized Randall Knight's treatment of statistical physics in his *Physics: A Contemporary Perspective* as being "uncharacteristically complicated and [in] need [of] revision." I based my criticism on the "preview" edition of his text. The "preliminary" edition, which I received too late to review, contains a substantially revised treatment that is very much improved.

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Cat Tales Reveal Footnotes to History that Give One Pause

On behalf of the late F. D. C. Willard and myself, I would like to congratulate Beatrix Ottoline Sophia von Schnurr on having joined the select ranks of uncredentialed authors who have received a byline in a leading physics publication. Of course, as made evident in her "Memoirs of Schrödinger's Cat"—as told to Daniel Kleppner (PHYSICS TODAY, November 1996, page 11)—Schrödinger belonged to her, not the other way around, and she was a domineering genius who more than lived up to her initials.

My professional relationship with Willard was quite different. In 1975, I wrote a paper on a proposed model for the spin exchange in solid helium-3, with the objective of submitting it to *Physical Review Letters*. When I showed it to another member of the Michigan State University physics department, he said, "Yes, it's a fine paper, but they will send it right back"—his reason being that I had used "we" everywhere and there was only one author. I called PRL and was told, "No, we'll just change the 'we' to 'I' everywhere." Now I understood the inexplicable use of "I" by some authors! To avoid that fate and also a complete rewrite of the paper, I hit upon the idea of simply adding a second author. I chose Willard, and the coauthored and peer-reviewed paper was duly published.[1]

Shortly thereafter, a visitor to MSU asked to talk to me, and when told I was unavailable, asked to talk with Willard. Everyone laughed, and soon the cat was out of the bag. You see, Willard's full name was Felis Domesticus Chester Willard (my cat Chester having been sired one summer by Willard, probably the scruffiest cat in Aspen).

Most of my colleagues thought it was a good joke but one or two felt it a bit disrespectful, and one who was an editor did not seem too amused. Nevertheless, Willard's reputation slowly spread.

I made a few reprints labeled "compliments of the authors" and signed by myself (handwritten signature) and Willard (print of inked paw), and I sent copies to a few acquaintances and also to a certain physicist in Grenoble, France. He later told me that at a meeting to decide who to invite to a conference, someone had said, "Why don't we invite Willard? He never gets invited anywhere." The reprint was shown around, and everyone agreed that it seemed to be a cat's paw signature. Perhaps that was why Willard never got invited, and neither did I.

Another physicist told me that whenever a supplicant visited him at the National Science Foundation and the conversation lulled, he would bring out the Willard paper. His habit may have had an effect on my own grant-getting efforts.

Willard's greatest triumph as a