used up in one bulb before it gets to the other. This explanation is similar to a description in the teacher's edition of the sixth-grade volume of the series *Science: Understanding Your Environment* (Silver Burdett, Morristown, New Jersey, 1972): "In a series circuit [of presumably identical light bulbs] the lamps grew progressively dimmer, reading from the negative to the positive terminal." The emphasis on the fact that the bulb nearest the negative terminal is the brightest suggests that the authors want to convey the impression that electricity (or perhaps the negative electrons) is being used up.

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10/91 *Denver, Colorado*

Zitzewitz replies: Mario Iona might be correct that some students may interpret "state of motion" to mean the spiral motion of the ball when it is in the tube, and that some may believe that "If it is in spiral motion, it will continue to move in a spiral" is a correct generalization from the two "If . . ." conditions he cites. My experience with students, however, indicates that most of them read textbooks with much less care than we might hope—certainly not carefully or actively enough to produce such sophisticated, if incorrect, generalizations. The 1992 edition of our textbook makes neither of the statements Iona quotes. As Richard Gunstone and Michael Watts write, "Language which is meaningful to teachers may, because of students' views of the world, have a quite different (even conflicting) meaning for students. If we are not sensitive to this, we can unwittingly reinforce the very view we want to change."[1] Thus when cognitive scientists study student learning, they might include in their student interviews questions of textbook interpretation.

Many student misconceptions not only have obscure origins but also are extraordinarily difficult to overcome. My experience with trying to correct student misconceptions about electrical circuits—specifically, the idea that a battery produces a constant current—shows that even university students find it very difficult to integrate what they have learned in separate contexts. On an examination in my engineering physics course, over 40% of the students stated that if the current in one branch of a parallel circuit is decreased, the current in the other must increase to compensate—this despite a clear textbook discussion of the independence of currents in the branches, completion of problems calculating currents, a demonstration showing the independence, and a laboratory exercise where students measured the current in one branch while changing the current in another.

As Jose P. Mestre describes in the box on page 59 of the September 1991 issue, overcoming student misconceptions requires not only correct and clear textbook expositions but an active teaching technique. All of us involved in teaching and textbook writing have an interesting and important challenge.

Reference

1. R. Gunstone, M. Watts, in *Children's Ideas in Science*, R. Driver, E. Guesne, A. Tiberghien, eds., Open U. P., Philadelphia (1985), p. 101.

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Reward Teaching as Much as Research

In the September 1991 issue (page 56), Jose P. Mestre presents a thought-provoking discussion of the "transmission model" and the "constructivist model," the main instructional practices found in American education today. If you recognize a degree of "constructivism" in your own career, then you are indeed fortunate.

That a "constructivist" teacher would need inordinate skill and talent goes without saying. Imagine leading students in discussions such as the example Mestre gives on page 58. That would require a fine touch, and not just for dealing with the technical aspects of science. In fact, a detailed knowledge of science may be less important than knowing when to insert the comment that maintains an appropriate atmosphere of inquiry. Experience suggests that constructivist teaching is the most effective—but what would motivate someone to expend the enormous effort needed to develop the requisite skills?

Years ago, teachers (never an economically advantaged group) were deemed sufficiently necessary to deserve some security. This was particularly true for those who taught tenets unwelcome in the political climate of their day. Thus arose the concept of tenure. In effect, society admitted that certain services were important and needed to be protected and nurtured. Currently, tenure decisions are not based solely on teaching. Often it seems that research credentials and grantsmanship are primary. Some cynics might suggest that tenure has become akin to the bonus system extant among investment bankers. The generation of large cash flows generates large overhead charges that can support university growth in eclectic ways. (The recent events at Stanford University come to mind.) Since continued growth is believed essential in universities as well as in business, a university must retain people who pull in such money. (Curiously, dynamical systems that continue to grow are considered unstable, but perhaps systems constructed by humans are immune to this rule.)

Teaching is a far different activity from research, and a particular individual may not be equally adept at both. Contributions to research are relatively easy to judge, but what about equivalent teaching criteria? Consider how this problem is solved in athletics: Professional teams know full well which college programs prepare pupils with the appropriate attitudes who are properly grounded in the fundamentals. Perhaps academics could construct a system in which the level of student preparation measures the effectiveness of the teacher; they might even devise an equivalence relation between measures of student training and of research contributions that would make accomplishments in either arena interchangeable.

Training people for any activity is difficult, but the long-term success of our national enterprise demands that we try. If poor teaching is a cause of our students' problems with science, isn't a solution at hand? Isn't teaching the core business of a university? If teaching and research achievements were acknowledged equally, physicists might make the effort necessary to become skillful teachers. Their students would be people with a knowledge of and interest in physics, some of whom might choose to become physicists themselves. Obviously, this scenario is unlikely if the reward system is biased toward research.

Could the physics community cope with such a shift in emphasis? One hopes so. The future looks rather grim if we continue to do "business as usual."

H. F. Bezdek
12/91 *Miami, Florida*

The 'Great Books' Approach to Physics

What should we be teaching our children in high school? I believe that a course based on any high school or college text currently available will be inadequate. Physics lives in the classic papers of the great physicists, past and present.

Don't our courses provide us with the contents of these papers in a more convenient form? Not really. The full force and freshness of the mind originally applied to the solution of the problem is invariably lost. As a student, I remember being struck by how well Fermi explained the Carnot cycle in his little book *Thermodynamics*. I understood why he was able to do such a good job when I later read Carnot. But while it is stimulating to see physics made over by a great physicist (consider the cases of Sommerfeld, Pauli, Landau and Feynman), physics was not made by one man or woman. Even the string men did not rise from the ground unbidden. Theodore Kaluza and Oskar Klein had to plant the dragon's teeth.

In each of our specializations, we see the living flow of physics every day. How can we let everyone in on the fun?

I believe that every child in high school should study the historical development of the physical sciences and mathematics. To set up such courses, the great classic papers of physics, chemistry and mathematics should be collected together. We want a set of books, or better, computer discs, describing the people who made physics, the problems they worked on and, most of all, their own words describing what they did: Galileo on Galileo, Newton on Newton, Boltzmann on Boltzmann, Einstein on Einstein, Feynman on Feynman. Simple reprintings or translations will not do. We must explain each part of these papers clearly to our students. Once this has been done completely, there will be no difficulty in providing abbreviated versions for every level of interest and ability. In this way, our children will be left in no doubt as to what science is and how it works.

What would be the role of the teachers in all this? By providing them with the finest science and mathematics course in existence, we could immediately address the problems of boredom and lack of qualification among high school science teachers. Having run through the course once, the teacher would have ample knowledge to supervise the students the next time around. In the last two years of high school, the students would, hopefully, be working mostly on their own, referring to the teacher mainly as an adviser. Doesn't this mean that some of the children might be studying gauge theory while others in the same class are still rolling balls down inclined planes? Should this frighten us? Only if we are wedded to the idea that the child reading about the Glashow–Weinberg–Salam model is in some way "better" than the child visiting with Galileo. As long as each student has found a real physical problem and is studying it in the company of the people who solved it, all is well. If we still wish to grade our children, test examples can easily be obtained. But the real examples turn up in the development of the subject and in the application of physics to other parts of science. Why have I never seen an electrostatics problem on the ion traps in neuronal cell walls, without which I couldn't think to write this letter?

The transition to the kind of creative chaos I am envisioning would most naturally occur by a series of bifurcations. For the first two years, everyone would get a rough "story of physics," so they would know what's on offer. Then the class would break into groups working on specific problems. The groups would then fragment as each student went forward at a different speed. As the system developed, the splittings would occur earlier and more violently.

Wouldn't all this cost an enormous amount of money? A year and a half ago, NSF awarded \$8.6 million in grants to encourage the improvement of science teaching in middle schools and high schools—one-thousandth the amount allocated to the Superconducting Super Collider, an allergic reaction to the US's perceived loss of leadership in experimental particle physics. Who but the students studying science in our high schools will restore this leadership? We can take the first step by making the best physics has to offer available to our children.

Alistair M. Wilson
12/91 *Tucson, Arizona*

Corrections

April, page 84—Edward L. Nickoloff (Columbia University) was left off the list of newly elected board members of the American Association of Physicists in Medicine. He was chosen to complete the unexpired term of Richard L. Morin, AAPM's 1992 president-elect.

March, page 23—The list of US groups participating in the Zeus collaboration at HERA should have included teams from the University of California at Santa Cruz and Pennsylvania State University. ■