A New High School Science Curriculum

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It is well known and rather passively accepted by the physics community that high school physics is a disaster area in most American schools. Physics is almost universally taught last in the science sequence. It is perceived to be the hard subject, suitable only for nerds—and only male nerds (are there any other kind?). Less than 25% of high school students attempt to take high school physics. This circumstance imposes three kinds of penalties: Physics loses a precious number of potentially gifted recruits; the rest of the sciences lose the advantage of students with a solid background in physics; and society loses citizens who have a grounding in the kind of critical thinking skills that a good physics course can generate.

In over 95% of our high schools, the standard science sequence is biology first, perhaps following some kind of science survey or qualitative Earth science, then chemistry and, finally, for the hardy survivors, physics. The logic of this ordering, which was apparently installed 100 years ago, appears to me to be alphabetical. (To be fair, physics is thought to require mathematics that high schools do not deliver until the junior year.)

A variety of attempts have been made to change this situation. Here and there, school systems have been induced to revise the order: physics, chemistry and then biology—which is the more standard order in European and Asian high schools. Although I do not know of all these US efforts, the P. K. Yonge Lab School, associated with the University of Florida, has been teaching science in the correct order since 1967.

The Illinois Math and Science Academy, in Aurora, Illinois (a public school where the students live in dormitories), teaches physics and chemistry first, then biology. That institution is also experimenting with integrated science, as is the Casa Roble High School, in Orangevale, California, and I'm sure, many other schools. The National Science Teachers Association program, articulated by Bill Aldridge, has a project called Scope, Sequence and Coordination of Secondary School Science. This builds in the cognitive science results of the 1950s–1970s and revisits basic concepts at successively higher levels of abstraction. Here, too, the emphasis is on a logical ordering of the subjects and a softening of the disciplinary boundaries. The driving thinkers who inspired Scope, Sequence and Coordination include physicists Robert Karplus, Arnold Arons and Lillian McDermott. Over the past several years, the Teachers Academy for Math and Science in Chicago, to stimulate discussion among educators, has stressed the pyramid of science in which physics provides the underlying basis for chemical structure and atomic reactions, and chemistry supplies the knowledge of molecular structure that is the basis of much of modern biology. In spite of these heroic movements, progress in changing high school science has been glacially slow.

Now something dramatic is in the wind that may well melt the glacier and give hope of accelerating progress far beyond the standard optimism of physicists. Superintendents of schools in New York and Chicago have recently announced their intention to require three years of science and math for *all* students. When all three subjects are required, what before had been merely logical now becomes a totally mind-boggling possibility: an "integrated" three-year science sequence for all students—job-bound, college-bound, science-bound. In this sequence each science course would stress general principles, some historical development and relevant applications; each would be inquiry and laboratory based. One could include applications to technology and to intrinsically interdisciplinary examples from ecology, Earth and space science, and issues of science and society.

In the logical science sequence, ninth-grade physics would have to be largely conceptual, based on what one hopes is a reasonable level of eighth-grade algebra. However, it would be a real physics course, *not* a survey course, not "physics appreciation." The course would be designed to pass students on to their next experience in science—chemistry, with a grasp of the structure of atoms. Such general principles as conservation of energy, concepts such as periodicity, probability and so on would be structured in the expectation that they will be revisited in chemistry and in biology. Chemistry would begin with molecule formation. Materials, reactions and structure would be dealt with on the atomic level. With entering students who are knowledgeable in physics, the chemistry (and biology) courses would be able to go much further or deeper. The chemistry course in turn would be designed to prepare students for biology. Biology would now deal with students who are comfortable with molecular structure and are ready for cells, genes, DNA, immune systems, nervous systems and biological mechanisms.

If three years of science is re-

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quired, then one has the opportunity to design all three years in a coherent manner. The high walls separating disciplines could be softened and often breached where it makes sense. The physics course could, from time to time, venture to apply physics to chemistry and biology as well as to some agreed-upon interdisciplinary topic that would be revisited in the next two years. Similarly, the chemistry discussions could be extended to redo a physics topic at a higher level of mathematical sophistication. (Remember that we also have a three-year math requirement.)

A three-year science sequence would need a scaffolding, with significant areas left open for teachers to develop. There should be a strong element of teamwork among the teachers, with periodic meetings (oh, where will they find the time?) to discuss progress. For example, the physics teacher could be invited into the biology class to discuss photon–electron processes during photosynthesis. Similarly, the chemistry teacher could step into physics to discuss chemical sources of energy.

A curriculum based on a three-year, logically ordered sequence should produce students who will be comfortable with science for the rest of their lives. One objective for the math–science sequence would be to provide a base of scientific knowledge and thinking skills that will enable non-college-bound students to proceed to a school-to-work transition program, starting in the third and fourth years of high school. Good high schools could organize a senior-year "science and technology for society" course for future Congressmen and TV anchorpersons. A properly structured sequence would improve the prospects for a solid undergraduate math–science requirement for liberal arts students. Finally, the curriculum would prepare interested students for advanced-placement physics, chemistry and biology, as well as a good course in Earth science or technology.

The task of restructuring the curriculum is the most challenging for physics. Paul Hewitt of the City College of San Francisco has been a pioneer in the development of "conceptual physics." Conceptual physics deals with the ideas and the process of enlarging our worldview. It relies much less on algebra than traditional physics instruction does and more on the crispness of concepts and their aesthetic value. It studies the practical, down to earth and relevant as well as the soaring of abstract imagination. Many of the proponents use this approach for teaching "liberal arts" students. I believe, however, that a solid ninth-grade physics course, constructivist, motivational, with a strong social context, is for *all* students: future auto mechanics, lawyers, computer scientists. Hewitt himself eloquently argues that stressing the understanding of concepts and the associated thinking skills is essential in all physics classes. He and his growing following feel conceptual physics has value even for physics majors.

But teaching conceptual physics isn't easy. In conveying real understanding, the teacher can't hide behind problem solving. It probably will feel like bicycling without hands. However, as part of the three-year program, conceptual physics could provide substantial returns to physics: the exposure of almost four times as many students to physics as now study it in high school. Like panning for gold, well-taught conceptual physics could uncover nuggets, student converts who might otherwise have been expended in law school or worse, if such a thing can be imagined. Among textbooks currently available to teach conceptual physics, I am aware of Hewitt's classic *Conceptual Physics* (seventh edition, Harper Collins, 1993) as well as *Physics: A World View,* by Larry Kirkpatrick and Gerald Wheeler of Montana State University (second edition, Saunders, 1995), and a new book by Art Hobson of the University of Arkansas, *Physics: Concepts and Connections* (Prentice Hall, 1995). An ambitious program in training physics teachers in conceptual physics is under way with Rich Olenick at the University of Dallas.

Developing a three-year curriculum that can be readily adopted by schools is an enormous task. Not only must the curriculum itself be designed, but an accompanying in-service program must help administrators and teachers adapt it to meet their own communities' needs and train many of the teachers to teach in a new paradigm.

A group of scientists (myself among them) and science teachers based at Fermilab, the Illinois Math and Science Academy and the Teachers Academy for Math and Science has begun to discuss the virtues and problems of creating a new science curriculum based on the assumption of a three-year science requirement. Such an effort will entail, ultimately, new books, new standardized tests, new teacher training. Our objective is to begin to design a three-year sequence consisting not of physics, chemistry and biology but of science I, II and III. This sequence would naturally be tuned to the widely accepted standards of what children should know at various stages in their educational experience. The American Association for the Advancement of Science's "Benchmarks," developed as part of the association's Project 2061, have been in formulation for a decade. The National Academy of Sciences has just issued a set of standards for science learning and assessment, and the National Commission of Teachers of Mathematics issued guidelines for high school mathematics standards a few years ago.

Preliminary efforts by the group of scientists and science teachers is being carried out at Fermilab, with the encouragement of Director John Peoples, and also at the Illinois Math and Science Academy, under Director Stephanie Marshall, as well as the Chicago-based Teachers Academy for Math and Science, led by Lourdes Monteagudo. We will begin by convening a small workshop of teachers and scientists to produce an outline for a three-year curriculum in which the first year, science I, is largely physics, the second year, science II, is largely chemistry, and the third year, science III, is largely biology. The outline will be the heart of a proposal to fill in the curriculum and help schools initiate pilot programs.

If the New York and Chicago goals catch on and a rapidly increasing number of schools adopt the three-year math and science requirements (a big if), we can expect to see a huge increase in science-literate citizens and voters. Thus encouraging this "trend" is about as important an activity as I can imagine if we are concerned about the future of physics and of science in general. But while the prospect of an explosive increase in science understanding raises goose bumps, it also evokes the skeptical inquiry, What's the catch?

The catch is always the same: We do not now have the teachers who can carry out such a program. I have not estimated the number of teachers that would be needed, but it must be in the thousands nationally. That shortfall would imply that we will need something like a 1% increase in the number of teachers in America. Curiously, the present job crisis among young PhDs offers an opportunity to attract such highly qualified scientists into the teaching profession. If we work fast, developing a new curriculum would, by itself, serve to accelerate the establishment of a nationwide three-year science requirement. As I was working on this column, on 21 February the Chicago School Board approved the plan for implementing a three-year math–science requirement by 1998. ■