linebacker makes a quarterback a part of the turf.

Two methods that allow for conceptual development are the learning cycle[1] and the conceptual change model.[2] In these inquiry-based methods, students are required to explore, discover, and, in many cases, change their ingrained perceptions of the universe.

Another aspect of teaching science, addressed by Giancoli, is the idea of cross-curricular teaching. True, we should not expect the biology teacher to teach the fluid dynamics of the circulatory system, or the chemistry teacher to teach the concept of cross sections when introducing nuclear chemistry. Yet teachers need to team-teach occasionally to show students how truly connected all of the disciplines are. At my former high school, I team-taught a lesson with the social studies department chair during his unit on World War II. He taught the political aspects of the Manhattan Project and I took on the military and scientific aspects. The students were quite surprised that two teachers of differing disciplines would take the time to teach in this manner, and their attention was not difficult to maintain.

As with any change, there will be plenty of system and procedural inertia to overcome. Tackling this hurdle will require systemic change in teacher preparation and professional development, which I thought Roger Tobin, Ramon Lopez, and Steven Bittenson addressed nicely (PHYSICS TODAY, January 2002, page 10.)

Lederman is certainly accurate in saying that the Third International Math and Science Study results should be a red flag indicating a serious lack in our public-school science classrooms, but let's not take tests to the extreme that our body politic is suggesting. Let's use them to generate dialogue about how to repair the problem, not to affix blame.

If inquiry-based teaching and learning are to truly take hold in this nation's science curriculum, time is a critical factor. Inquiry comes at a cost in both dollars and time. In Richard Rhodes's book, *The Making of the Atomic Bomb* (Simon & Schuster, 1986, p. 108), Theodore von Kármán, seen by most as the architect of the space age, said of his science education, "At no time did we memorize rules from a book. We sought to develop them ourselves." Rhodes added, "What better basic training for a scientist?" If it worked for von Kármán, it will work for our children. As Plutarch said, "The mind is not merely a vessel to be filled, but rather a fire to be kindled."

References

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The proposal by Leon Lederman to teach physics in the 9th grade seems like a call for reviving, no doubt with modifications, a course that existed in New York State for decades. That course included topics in chemistry, and certification to teach it required at least two years of physics and two of chemistry.

Because the 9th-grade population is so diverse, the course has to be adaptable for different groups. The February 2002 issue of *The Journal of Research in Science Teaching* gives many examples of the problems faced by science teachers in urban settings.

Sadly, in the public schools of Norwalk, Connecticut, the 9th-grade science course is Earth science. That may be because so few of the teachers have had more than one year of physics.

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Leon Lederman argues for putting physics experiences—whose understanding is enhanced by sketching speed-versus-time graphs, applying Galileo's "isolate the system" idea, and drawing free-body diagrams—in the 9th grade with an aim toward molecular biology in the 11th grade. I suggest an ecology-based biology course in the 9th grade.

An ecology course, while including graphical analysis and the concept of the isolated system, would stress developing an understanding of and appreciation for interconnected and interdependent systems. Students might then have some rational basis for deciding that "individuals in community" is often a more fruitful conceptual tool than those offered by either the worldview of extreme individualism or that of extreme collectivism. Furthermore, physics teachers might be encouraged to read and study George Gaylord Simpson's "Biology and the Nature of Science," in which he said,

> I suggest that both the characterization of science as a whole and the unification of the various sciences can be most meaningfully sought, not through principles that apply to all phenomena but through phenomena to which all principles apply. . . . [Those] phenomena are . . . the phenomena of life.
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> Biology, then is the science that stands at the center of all [natural] science. . . . And it is here, in the field where all the principles of all the [natural] sciences are embodied, that science can truly become unified.[1]

Reference

1. G. G. Simpson, *Science* **139**, 81 (1963).

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LEDERMAN REPLIES: Herding cats must be absolutely trivial compared to accomplishing anything in educational reform! Nevertheless, we cannot surrender. Education, even the subset we call science education, is an enormously complex system and, as I have often stated, the resistance to change is impressive. That is why the science education curriculum in K–12 is so poor and so antiquated.

About 10 years ago, I decided to spend a significant fraction of my time to try to create and "sell" a coherent three-year science curriculum. Colleagues and I (collectively, the ARISE group, American Renaissance in Science Education) have thought through the steps we must take to achieve a physics-chemistry-biology (P-C-B) sequence in at least a majority of US high schools. We are making progress; with more than 300 high schools doing it right, we have only 24 392 to go.

Three years of science in a sensible order, threaded with three years of math, would be a major advance. Of course it would only be a first step in reform of pre-K to 16 schooling. But practical politics mandates that science education reformers move one sharply focused step at a time. Each step must be capable of amassing a consensus among teach-