Letters

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the best way to understand Newton's gravity is first to study it, then to study Einstein's general relativity, and finally to recognize how Einstein's theory reduces to Newton's theory in the special case in which humans normally experience gravity.

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Leon Lederman's much appreciated commentary is 90% excellent. It strongly urges that high-school students study three years of science and learn the process of science as well. I disagree with one major point, however: The traditional order of biology, chemistry, and lastly physics makes much more sense than the reverse order Lederman advocates. Here's why.

▷ Lederman argues that 9th-grade physics would transition into 10th-grade chemistry, which in turn segues into biology, each course building on the previous. I take this to mean that the 11th-grade biology teacher would have to be able to teach the physics of biological processes, presumably including protein synthesis, muscle action, and DNA replication. But isn't it a bit much to expect high-school biology teachers to cover physics at all, much less something so sophisticated?

▷ I am hardly the first to point out that students learn slowly and gradually, and that they learn better when starting with the concrete, followed by concepts and analysis. Shouldn't students know something about the structure and function of DNA and proteins before being given a physics explanation of what holds these macromolecules together and what physically makes them interact as they do in the cell? Teach the biology first, then the physics explanation later. First the phenomenon, then the explanation.

▷ Biology is more accessible to young people than the conceptually more sophisticated physics. Ninth-grade physics would have to be "baby physics." Students can understand physics better if they remember a tiny bit of algebra. Learning physics, with its conceptual difficulties, is much more possible in the 11th grade, after students have learned in biology and chemistry what science is like. Being more knowledgeable mathematically will help too. Can we really expect most ninth graders to understand the meaning of an inverse square law—or even mv^2/r, or Faraday's law? Surely trying to teach the physical nature of even the simplest chemical bonds—exclusion principle, wave interference—needs to be done by the physics teacher. And not before students have heard of chemical bonds and what they do.

Physics is the most basic of the sciences, even the pinnacle. Physics offers the ultimate explanations of how things work, the explanations most removed from ordinary reality. I emphasize again: first the phenomenon, then the explanation. To teach explanations before students know the phenomena doesn't make sense. And we should not expect chemistry or biology teachers to teach physics. The final course in the triad, physics, should definitely include physics applied to biology as one of several culminating points. Another might be cosmology.

As a footnote, I have team-taught, with chemistry professors, courses for teacher candidates. It's tough, in part because chemists view the atom very differently than we physicists do. Also, I'd like to emphasize that students generally know much less than we hope they do, even in biology. Thus normal descriptive biology should not be downgraded to totally favor biochemistry.

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Lederman replies: I am most impressed by Michael Bretz's scholarly letter, which qualified him to lead the crucial movement for reform of science education. I will certainly study the work of Bernard Lonergan, which seems to articulate the thinking that has motivated the ARISE (American Renaissance in Science Education) program. Bretz also touches on an issue that we did not have time to cover: The revolution must extend down to kindergarten and before. Young children must be inoculated against math phobia and must be continually exposed to inquiry-based science, consisting mostly of process early on, liberally sprinkled with Bretz's Aha! moments. Descriptive nature, natural science, ought to precede ninth-grade physics. I will reread this encouraging letter many times.

The other letters are discouraging because they illustrate my failure to make the case, which I believe should be logically obvious and which is authenticated by the exuberant successes of some hundred schools around the nation. Those successes should also be set in the context of, say, the Third International Math and Science Study results, attesting to the failure of US high schools to compete internationally in science. The results tell us that something is seriously wrong with the way we teach science. Yet the forces of stasis will find reason after reason for the status quo. Ian Thomas hesitates to introduce electricity because its concepts are hard to grasp! Yet, electricity is all around the house, it is concrete, important to our daily life, and hardly exotic. Nevertheless Thomas is willing to include general relativity, after Newtonian gravity. I am sympathetic to paralleling history whenever convenient. However, teaching pre-atomic chemistry and pre-molecular biology makes no sense.

Douglas Giancoli's letter is more hopeful and I believe that a few hours (with a few beers) could convince him that physics, taught conceptually, is not baby physics, but can be a solid, meaningful experience that uses the math taught in ninth grade to provide explanations for everyday phenomena that surround the students. The point of putting physics before chemistry is that it should provide the tools and concepts, and especially the concepts of atoms, to explain some major chemical ideas—for example, the periodic table, gas laws, or the formation of the chemical bond. Conceptual physics is also the unique introduction to all students of how science works. It is applied to the extremely simple phenomena of why things move, of falling bodies, uniform motion, the simple pendulum, and so forth. One can't really believe that ninth-grade biology with hundreds of new words to be memorized is the correct way to introduce high-school students to a disciplinary science! Physics concepts in ninth grade serve first to apply the ninth-grade algebra and second to teach how science works, including such vast syntheses as achieved by the theory of gravitation.

Look at how the infant (scientist in the crib) learns about the world: It's all physics. Also, we don't want biologists to use physics to explain DNA, but we want biology to deal with DNA and, folks, DNA is a molecule, and molecules are made of atoms. Comfort with atoms will give students a sense of how those atoms can hook together in different ways to provide different functions. Here, qualitative thinking serves us well.

We never suggest using explanations before phenomena, but we do insist on providing the tools by which explanations can follow phenomena. The explanations can follow the phenomena after the basic ingredients have been learned. If more physics than was taught in ninth grade is needed in, say, a biological process, then by all means invite in the physics teacher. This will enrich the physics that was learned at an admittedly low level and encourage the taking of advanced physics courses after the three-year sequence. The same scenario can be applied for the chemistry that biologists must know.

In all of this, we must not forget the objective: to bring the science way of thinking to all high-school graduates. I believe doing so will in no way hurt future scientists or engineers. The curriculum should be rich enough to give them the advanced courses that can profitably build on the firm, conceptual, and process-rich sequence I am trying to describe.

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An Earlier Bar to Rescaling Units

Solomon Golomb, in his letter to PHYSICS TODAY (October 2001, page 12) has proposed that physical quantities—for example, time and temperature—be expressed in logarithmic scales, preferably based on the decibel system widely used by engineers.

Years ago, the late Lewi Tonks and I made the same proposal,[1] but specifically for measures of pressure or vacuum. We proposed to use the common logarithm (base 10) of the absolute pressure in bars, and to name the unit step on that scale "one boyle." We noted that "one deciboyle," one-tenth of a boyle (about 12%), would be a fair measure of the precision with which extremely high or low pressures are measured in all but the most precise work. Our paper referred to similar earlier proposals and mentioned a table of constants to be added to 10 times the logarithm of pressures expressed in various units (for example, torr, inches of mercury, psi, and atmospheres) to convert them to the deciboyle scale. It also gave a list of examples ranging from the lower limits of the ionization gauge (–140 dB) to the pressure at Earth's center (65.61 dB).

Besides the *Nature* article, our proposal was presented to the American Society of Mechanical Engineers at their winter meeting in 1964[2] and was described to and discussed by readers of the trade journal *Research/Development*.[3] Predictably, there were various alternative proposals. When readers were polled by the journal, 43% favored "retaining the present system"—whatever that is!—while 41% favored some form of logarithmic scale. Not all of the 41%, however, favored our designation of the bar as the base of the scale. Many said that we already have a logarithmic system in the prefixes (milli, micro, and so forth). We responded to them at length in the March 1966 issue, noting "an irrational component of conservatism in such matters, which has been noted and deplored by most students of creativity."[3]

To my knowledge, that was the first proposal to apply the decibel system to other than acoustic measurements, and the only one I have been aware of before Golomb's letter. I am unaware of any formal action on our proposal.

I wish Golomb more success with this proposal than we had 35 years ago!

References

1. G. C. Baldwin, L. Tonks, *Nature* **203**, 633 (1964); *Bull. Am. Phys. Soc.* **9**, 476 (1964).
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3. G. C. Baldwin, L. Tonks, *Research/Development*, F. D. Thompson Publications, Inc., February 1965, and comments in the issues of September 1965 and March 1966.

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Is The Universe's Expansion Accelerating?

A Search and Discovery article titled "Farthest Supernova Strengthens Case for Accelerating Cosmic Expansion" (PHYSICS TODAY, June 2001, page 17) deals with the present state of a central question in