WHY NOT TEACH 'PHYSICS FOR THE FUN OF IT'?

Instead of asking why few students take physics, suppose we ask our best physicists why they are physicists. My guess is that most will speak of the enjoyment of thinking about observations, forming and testing hypotheses, and the excitement of seeing it all fit together. Contrary to the suggestions made by some correspondents in the April issue (page 112), they aren't physicists because physics relates to space travel and energy resources, nor because everybody was required to take physics. They're in it for the fun of it.

Marlys Stapelbroek's letter spoke of the difficulties of "thinking experimentally." It seems to me that the time to start showing our future physicists the fun of thinking experimentally is when they are children in the early grades of school, before their natural curiosity and penchant for experimenting have been beaten out of them with "Don't touch!" and "Listen to the teacher for the right answer."

I have been involved as an author in two different science curriculum projects. In both the central purpose was to show the enjoyment of finding out about the world around us. For one of these projects I wrote a "module" called "Evidence of Invisible Systems." The first thing the students were asked to do was to look out the window and figure out how we know whether the wind is blowing. This awareness of how deductions are drawn from observations was eventually extended to the discovery of crystal structures by x-ray diffraction studies. Even the most sophisticated experiments must ultimately produce results that our senses can detect.

In the other project, a text for college freshmen who did not plan to go further in science (*Physical Science for Non-Science Students*, the PSNS project), the approach was to have the students do a simple experiment with a puzzling result and to encourage them to think about possible explanations. This is better science than to use the experiment to demonstrate a law that has been expounded in the textbook. If Stapelbroek had learned to think experimentally through such approaches, from fourth grade on up, she might have been able to enjoy applying her excellent math skills to physics.

To increase our supply of physicists and others sympathetic to the physics community, we must share with everyone, at an early age, the nature of the enjoyment of physics.

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Training Students for Future Flexibility

I am continually amused by the discussion of science education in high schools. My own unique experience appears to be a counterexample.

I had an excellent high school education at Washington High School in Rochester, New York. The science courses were minimal, and I did not even take advantage of those mathematics courses offered. In my senior year I chose not to take the fourth-year courses in trigonometry and solid geometry and instead took voice training and choir. The musical training has enriched my life by enabling me to participate in choral groups.

During the summer after my high school graduation, I picked up the trigonometry and solid geometry textbooks, read them and easily passed the Cornell entrance examinations. I took calculus during my first year at Cornell, and also learned all the physics and chemistry I needed. I never felt I had missed anything by not having learned this in high school. After graduating in electrical engineering from Cornell, I eventually switched to physics and did a PhD in experimental physics at Princeton. Formal course work was not stressed. The student was expected to pass a general examination in physics when he felt he was ready for it. Nobody cared whether he learned the material from formal courses or by sitting in the library.

After finishing my PhD I traveled to Europe and Israel and worked for a while in electronics, nuclear engineering and experimental physics be-

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fore ending up as a theoretical physicist working in nuclear physics, solid-state physics, particle physics and basic quantum mechanics. I have had many opportunities to compare my background with those of colleagues and students in Europe and Israel who had learned much more science and mathematics in high school than I had. I generally found that mine was far superior.

In high school I learned how to think, how to study and how to express myself in acceptable English. I learned enough of two foreign languages, Latin and German, to provide a basis for learning two more later on when I needed Hebrew in Israel and French in France. I picked up some typing skill, just for the fun of it, when typing was considered a subject only girls who had no hope of a college education and would need to work as secretaries. I now type and edit directly into a terminal with a speed that surprises today's computer whiz kids, who do not expect such skills from my generation. Above all I learned how to learn new things, to pick up new ideas and new concepts, and to abhor rote learning of facts without understanding something about the reality behind them and the relations between them. I learned that there was always more than one way to solve a given problem and that it was more fun to look for new ways instead of blindly following the standard method in the textbooks.

When I entered Cornell in 1938, the curriculum in electrical engineering included only one semester of electronics. The faculty assured us that although we students were enthusiastic about ham radio, there was no future in electronics. All the jobs were in power engineering, power transmission and so on. Fortunately I had learned from my high school experience not to be constrained by such rules and studied extra physics. Thus I learned Maxwell's equations (then actually opposed by the engineers) by listening to physics courses not in the electrical engineering curriculum.

Physics and technology have changed a great deal since 1938, when the computer terminal did not exist, even in dreams, and the faculty of one of the best American engineering schools believed that there was no future in electronics. Even more dramatic changes can be expected in the next half-century. High school education should be aimed at giving students the broad background and flexibility that they will need to face this changing future and to go beyond the subject matter that today's best teachers think is important.

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Is Resonant Tunneling Transistor a Reality?

In their article "Quantum Electron Devices" (February 1990, page 74), Federico Capasso and Supriyo Datta note that "conceptually, the simplest way to build a resonant tunneling transistor is to form a contact with the heavily doped quantum well of a double barrier." The authors state that "this approach is, however, fraught with major technical difficulties, and attempts in this direction have not yet succeeded."

On the contrary, this approach, first proposed by Bruno Ricco and Paul Solomon,[1] *has* been used to fabricate resonant tunneling transistors.[2,3] In these devices, the quantum well of an AlGaAs/(In)GaAs resonant tunneling double barrier was doped heavily p-type, and ion implantation was used to make contact to the quantum well.

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CAPASSO REPLIES: The statement in our article quoted by William R. Frensley, Mark A. Reed and Alan Seabaugh accurately reflects the experimental situation in that neither their reference 2 nor reference 3 describes a working resonant tunneling transistor. The device of reference 2 exhibits negative transconductance ($dI_C/dV_{BE} < 0$, where I_C is the collector current and V_{BE} is the base–emitter voltage), while no peak is observed in I_C as a function of the base current I_B (at constant collector–emitter voltage V_{CE}). Since physically the effect of increasing I_B must be the same as that of increasing V_{BE} (that is, suppression of resonant tunneling and attendant decrease of I_C above a critical V_{BE} and I_B), the claim that the observed negative transconductance is a manifestation of resonant tunneling transistor action is unsubstantiated. In the device of reference 3, on the other hand, no negative transconductance is observed. Finally, both devices have unacceptably large base resistances ($\gtrsim 1$ kΩ) for III–V bipolars. This has serious consequences for the operation of the device, as shown, for example, by the large collector-to-emitter offset voltage in the collector characteristic.

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Oratory and the Overhead Projector

The opinion expressed by John Rigden (March, page 73) that the overhead projector has caused us to lose our oratory abilities is off-target. I question first his assumption that physicists and other scientists *used to be* good orators. I also note that the primary purpose of an oration or speech is quite different from that of a talk or lecture accompanied by transparencies. A well-turned speech should inspire an audience to action or to a new frame of mind. Imparting information or understanding is secondary. Oration is of great importance to religion and politics, for example; Winston Churchill and Adolf Hitler come to mind.

A lecture or talk accompanied by transparencies has a different purpose: to convey information, of which a fair fraction should be *understood* and *remembered*. Understanding and knowledge are clearly not an objective of most speeches. (I venture to say that oratory can be a danger to science, as illustrated by the movement of "scientific" topics such as nuclear power, pollution and the greenhouse effect into the realm of political and religious oratory.) Visual aids greatly enhance our ability to remember spoken words. The effective use of an overhead projector can be invaluable in imparting understanding in science.

What Rigden could complain about is the frequent misuse of transparencies. Eighty percent of the transparencies used at scientific conferences are not "well turned," and 80% of the verbiage accompanying the remainder is also not "well turned" and has never been rehearsed. Though the fraction of good talks is small, I wager that things would be worse without overheads. The real problem began when our future scientists decided not to pay attention to high school English and writing classes, and few ever