Readers weigh in on how to teach physics

As a longtime teacher of college-level physics, I read with interest Ricardo Heras's Commentary on traditional versus creative styles in solving physics problems (Physics Today, March 2017, page 10). He has clearly been bitten by the excitement and satisfaction of studying physics, and he is already thinking deeply about how it can best be presented to students. My guess is that he will someday be a very highly regarded teacher.

I also think, though, that the traditional textbook problems Heras disparages have considerable value. Yes, we have all had (and probably were ourselves) students who can grind out an end-of-chapter or test problem without really internalizing the physics involved. But that is not the primary goal I have in mind when I have my students, particularly first-year students, do the problems.

Heras's model of a creative problem-solver is Richard Feynman, a rightly revered figure. But most of us, and most of our students, are not Feynman. I cannot expect my first-year students to develop deep physics insight. Before insight comes command of the foundational knowledge and techniques of the discipline, and my students are in desperate need of accruing practice in setting up and working through problems. The inevitable disappointment of seeing that their answer does not match the one in the back of the book and having to diagnose what went wrong is often the most educational aspect of the work. At higher levels, having students dig out an old-fashioned table of integrals and see how to compute an expectation value by hand—as Erwin Schrödinger might have done—gives them a sense of the nitty-gritty that underpins the insights of great creative minds.

Insight and expertise accrete over years of such grinding practice. Developing intuition in physics—or in any challenging discipline—is no different from learning to play a sport, speak a new language, or play a musical instrument proficiently: practice, practice, practice. Each boring problem is an incremental step along the climb, an investment that will eventually pay off in the form of a coherent foundation of knowledge and a grasp of techniques that will last a lifetime.

I have witnessed the evolution from blackboard- and overhead-based "static" lectures to powerful in-class computer and projector systems and laboratory sensor-interface units being used to illustrate concepts, calculations, and phenomena in ways I could only have dreamt of when I began teaching. But before a problem is thrown to the computer, it always goes up on the board first to have its physics, units, mathematical nuances, and orders of magnitude examined. To be sure, many traditions are inertia incarnate, impediments at best and destructive at worst. But not all are without virtue, and the best can be adapted to the times.

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Ricardo Heras writes that the basic courses in his first two years at University College London were disappointing. He says, "Most of my lecturers followed traditional teaching approaches based heavily on solving standard problems and learning by rote, with no hint of free inquiry or discussion."

My experience at the Colorado School of Mines in the early 1960s, where I worked for a degree in geophysics, was entirely different. I had all those basic courses, and frankly, I used them to learn. My interest in seismology started in middle school in Los Angeles because of the regular occurrence of earthquakes there. I devoured *Elementary Seismology* (1958) by Charles Richter. While in high school, I visited the seismological laboratory at Caltech several times. I was greeted cordially, and my questions were always answered.

In my first year at the School of Mines, I discovered an earthquake swarm in the Denver area.[1] Its origin was under contention, with the consensus view being that the earthquakes were spread over a 30-mile range and an alternative view being that they were the result of saltwater injection into a deep disposal well.

I took it as a research opportunity. The School of Mines was and is a small institution, with great freedom of inquiry and action. I located the pumping records for the well and then correlated that information with the energy released by the earthquakes. I found that with several weeks' delay, the energy released was proportional to the volume of liquid injected. Meanwhile, the US Geological Survey had installed seismometers close to the well, and the information from them seemed to confirm that the earthquakes were attributable to the pumping.

I caught up with a geology professor at a coffee shop and quizzed him about the Denver geology. At first he was reluctant, thinking I was a grad student trying to shortcut my research. After I explained my position and my interest, I spent 45 minutes trying to absorb the flood of information he provided.

My work led to the actual seismograms for the earthquakes. That, in turn, led to the discovery that a second earthquake event in these particular records had come almost immediately after the first. When the second event was removed, the earthquake locations all resolved around the well.

I used the materials taught in the early classes, including equations I learned in physics lab, the Fortran programming class I was taking, and other materials. So I found the basic classes not disappointing but rather a toolshed to dig out answers from conflicting data. With an open mind, an open campus, and a hunch, I was able to move from "I believe" to "from these data I conclude."

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I presented my data, and soon the institution came to agree.

Reference

1. J. H. Healy et al., *Science* **161**, 1301 (1968).

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Although one can sympathize with Ricardo Heras's plea for more creativity in physics teaching, the entire structure of physics education is currently founded on mastery of content, as reflected in tests taken at various stages. Those tests determine whether the student is qualified for promotion and even for admission to the PhD program.

To modify the didactic structure in favor of creative learning wouldn't accomplish the goals of physics departments as they are presently structured. For one thing, the time consumed for such learning would surely be much greater than for the current lecture–lab format. Of course, one could assign projects such as I have during my physics teaching career in the 1980s to early 1990s, but those would be *outside of class time*. Hence, they do not facilitate learning by supporting independent student creativity in class.

Heras mentions *The Feynman Lectures on Physics*; that three-volume work exemplifies its author's unconventional approach to physics teaching. But even today most physicists I know look at it as an interesting supplement to their undergrad courses and not as a standalone text.

The very reason Feynman's teaching and methods wouldn't work in physics departments as currently established is spelled out by Heras himself in his Commentary (page 11). He says, "Feynman's lectures successfully omitted proposed problems. His teaching style is also exemplified in the noncredit, no-homework, no-registration, tuition-free Physics X course he offered at Caltech."

What physics department today could even remotely entertain such a course? I am not saying it could never work, but it would require a radical rethinking of physics pedagogy and would come up against the existing system for promotion and qualification and for how we integrate students into the formal university course system.

Perhaps the optimal time for free inquiry might be when Heras pursues his PhD. Then he can find original expression for his curiosity, creativity, and inquiry. Of course, to reach that point, he will have to pass rounds of comprehensive examinations, and those will entail solving a lot of "traditional" problems.

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▶ **Heras replies:** Cameron Reed suggests that at the PhD level, a physics student will have worked lots of standard undergraduate problems and can finally acquire "a sense of the nitty-gritty that underpins the insights of great creative minds." I disagree. Richard Feynman, Julian Schwinger, and Lev Landau, for example, did not need a PhD to acquire that sense. Each published his first paper as an undergraduate.

Intuition in physics is, for Reed, a matter of "practice, practice, practice." Again, I disagree. Intuition is the key to, for example, imagining a new sport, inventing a new language, or composing a new symphony. To reach any of those goals, practice is necessary but not sufficient. I believe intuition triggers creativity, which is characterized by a crisis occurring when one imagines a plausible