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

idea that seems inconsistent with previously established ideas (see my essay, "Individualism: The legacy of great physicists," PHYSICS TODAY online, 25 October 2013). One needs a passionate desire to solve such a crisis.

Philip Stahl clearly describes the current role traditional exams play in the formation of a physicist. Unfortunately, mastery of content is often taught at the expense of free inquiry and creative thinking. To paraphrase Albert Einstein, "The value of a college education is not the learning of many facts but the training of the mind to think."

Stahl claims that "to modify the didactic structure in favor of creative learning wouldn't accomplish the goals of physics departments." I think those goals should be critically reviewed. For undergraduate students, physics departments should be shelters for creativity and not solely examination factories. Regarding Feynman's Physics X course, Stahl asks, "What physics department today could even remotely entertain such a course? . . . It would require a radical rethinking of physics pedagogy." Precisely! After more than five decades of traditional physics teaching, I say it is time for physics departments to make a place for creative teaching.

I was invited by PHYSICS TODAY's editor to write "on how you are being taught physics and—more important—how you would prefer to be taught physics." I took the challenge as an exercise of academic integrity. I received positive comments from outstanding physicists such as Freeman Dyson, Frank Wilczek, and Eugene Parker. In particular, Dyson gave me the following advice: "I agree with you that the time spent in formal class-room lectures and coursework is mostly wasted. You don't need all that stuff to do science. . . . My advice to you is to skip the classes as much as the system allows, and get to work on a real problem. When you work on a real problem, you quickly find out what you really need to know."

Most of my professors were uncomfortable with my essay. Some said that I was an atypical student and that their traditional teaching had worked well so far. Unfortunately, I can say from experience that "atypical" students face many difficulties in traditional physics departments. Despite having published six papers (see www.ricardoheras.com), my institution has denied me financial support to finish my undergraduate studies. Tradition is indeed strong in my department! But as Mark Twain wrote in *The Adventures of Tom Sawyer*, "Often, the less there is to justify a traditional custom, the harder it is to get rid of it."

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Wastefulness not always a result of progress

Charles Day, in his column "Olive spoons and terrapin forks" (PHYSICS TODAY, February 2017, page 8), seems to lament the use of LED lighting as decoration because it uses energy that would otherwise never be consumed. Making the leap to the Internet of Things and the usual milk-carton example, he argues that wastefulness is a by-product of technological progress. However, if the LED display were the critically acclaimed work of an artist, it would still be as wasteful of energy, yet also pleasurable and beneficial.

Similarly, the Internet of Things may promise a notification that my milk is sour, but one can easily imagine having the carton call the milkman for a delivery rather than simply texting me.

That is the approach with POEM Technology's monitoring system, which optimizes oil deliveries by reading and uploading heating oil tank levels, in turn allowing suppliers and consumers to fine-tune scheduling. Rather than being wasteful, the monitors enhance efficiencies by eliminating excess deliveries and their greenhouse gas emissions. Perhaps the real promise of the Internet of Things comes when the market realizes the value of such a closed-loop system. I do not want to get a text from my milk carton, but I would like to see the milk truck show up automatically, like it did when I was a child.

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