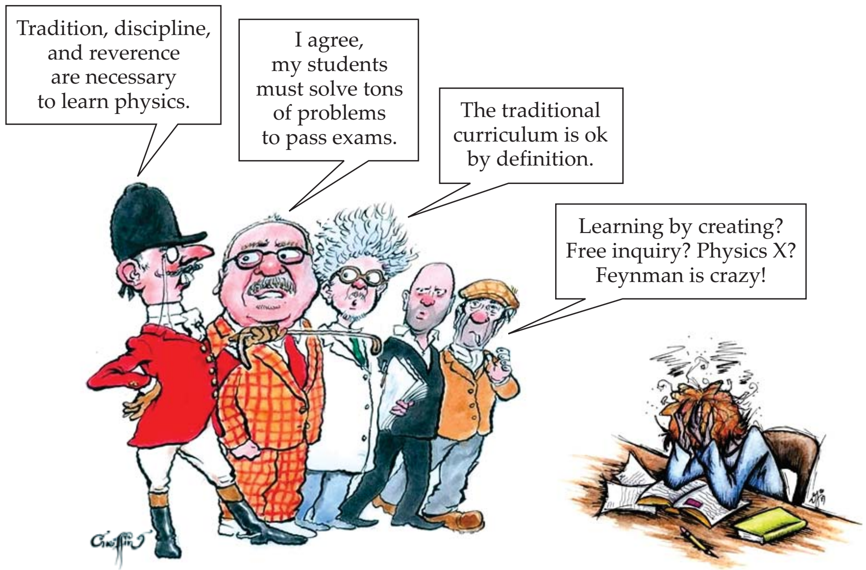
READERS' FORUM

Commentary

How to teach me physics: Tradition is not always a virtue

Physics is the most exciting endeavor I can imagine. That is why I want to become a physicist and join what Richard Feynman called "the greatest adventure that the human mind has ever begun."[1] Now, after my second year of undergraduate studies in astrophysics at University College London (UCL), I want to comment on some of the vicissitudes I have experienced while being taught physics.

The basic courses of my first two years were disappointing. They didn't really give me the opportunity to join that greatest adventure. 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. They seemed to be convinced that we would understand physics through that method. I was not enthusiastic.



TRADITIONAL PHYSICS TEACHERS teach us to swim on the surface but not in the deep, where, as Steven Weinberg says, "the unclear, uncharted areas of science can lead to creative work" (*Nature* **426**, 389, 2003).

Traditional teaching

My fellow students and I spent a lot of time and effort solving textbook-style problems. But we didn't really understand physics by doing that. In practice, we were mostly trained to use problem-solving techniques. Feynman touched on that failing when he said, "I don't know what's the matter with people: they don't learn by understanding; they learn by some other way—by rote or something. Their knowledge is so fragile!"[2]

I felt that fragility. The time crunch of a heavy course load forced me to memorize a lot of equations and mathematical procedures in order to pass my physics exams.

As time passed, I forgot many of the things I had studied. Noam Chomsky, interviewed in 2012 for the Learning Without Frontiers Conference, put it best when he said,

> A person can do magnificently on a test and understand very little. We've all had the experience of "acing a test" and forgetting everything two weeks later. . . . Passing tests doesn't begin to compare with inquiring, searching, pursuing topics that engage us and excite us. In fact, you will remember what you discover—if you pursue this kind of learning.

The aspects of physics I have understood best so far are those I have studied for pleasure. I understood special relativity better when I derived the Lorentz transformations in a different form.[3] This task was much more exciting than the usual assignment of calculating the length contraction of a rod. I understood Maxwell's equations better when I reviewed the Helmholtz theorem[4] and this task was far more thrilling than calculating the electric field of a charged sphere.

Traditional teaching methods urge us to perform standard calculations that rarely spark our creativity. Being immersed in such teaching, I feel trapped in a labyrinth whose exit can only be found by solving a ton of mostly uninteresting textbook problems.

The idea that solving such problems is not the best way to understand physics was succinctly expressed by Dieter Nachtigall:

> Pupils can often solve what textbook authors call "problems" without understanding the physics concepts involved in them. Such "problem solving" often exhibits nothing else than the ability to find some appropriate equations, put them together, manipulate them algebraically, fill in figures and finally come out with the "correct answer." A student can be good with the formulae but may have understood nothing about the physics behind them.[5]

Learning by creating

A robust alternative to traditional teaching is one that prioritizes creative thinking. That is the approach that Feynman strongly emphasized. Laurie Brown, a former pupil of his, comments that

> Feynman stressed creativity—which to him meant working things out from the beginning. He urged each of us to create his or her own universe of ideas, so that our products, even if only answers to assigned classwork problems, would have their own original character.[6]

Feynman's way of teaching is perhaps best described in three words: learning by creating. As he said,

> It's the way I study—to understand something by trying to work it out or, in other words, to understand something by creating it. Not creating it one hundred percent, of course; but taking a hint as to which direction to go but not remembering the details. These you work out for yourself.

In a letter to a student asking for advice, Feynman touched again on that point:

> All you have to do is, from time to time—in spite of everything, just try to examine a problem in a novel way. You won't "stifle the creative process" if you remember to think from time to time. Don't you have time to think?[7]

The problem is, however, that as students we are often not given proper time to think! We are instead overwhelmed with solving problem sets, writing lab reports, and worrying about passing exams. Remarkably, Feynman emphasized creativity in physics until his very last days. He wrote on his blackboard shortly before he died, "What I cannot create I do not understand."

The Feynman Lectures on Physics clearly exhibit their author's unconventional approach. David Goodstein (PHYSICS TODAY, February 1989, page 70) says of the lectures,

> If his purpose in giving them was to prepare classes of adolescent boys to solve examination problems in physics, he may not have succeeded particularly well. . . . If, however, his purpose was to illustrate, by example, how to think and reason about physics, then, by all indications, he was brilliantly successful.

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. Students met weekly, and the curriculum consisted of whatever they felt like discussing. The primary focus was to promote a culture of free inquiry and joy toward the subject. In the lectures I have attended so far at UCL, the idea of enjoying physics has not even been raised.

Feynman said,

> The best teaching can be done only when there is a direct individual relationship between a student and a good teacher—a situation in which the student discusses the ideas, thinks about the things, and talks about the things.[1]

Such teaching is mostly absent from my current physics education.

As a student, I have not yet been able to reconcile the traditional approach with my firm conviction that the best physics teaching puts a premium on creativity and free inquiry. Feynman has shown that such creative teaching is possible.

References

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Ricardo Heras
(ricardo.heras.13@ucl.ac.uk)
University College London
London, UK

LETTERS

Approaches to studying our history

I share Matt Stanley's view that studying the history of our subject enriches our perspectives as practicing physicists ("Why should physicists study history?," PHYSICS TODAY, July 2016, page 38). In my talks to the nontechnical public and in presentations of new results to colleagues, I try to emphasize the complex network of chance influences, mistakes, collaborations, and controversies that lie behind discoveries conventionally caricatured by attributing them to one person.

Stanley and I part company when he complains about those who interpret the science of the past in terms of what we know today: "the bugbear of . . . Whig history." Of course, it is essential to study scientific advances in the social, economic, and cultural context of their times, as professional historians do. But Whig history is a complementary activity, justifiable on several grounds.

Our scientific predecessors are celebrated largely because of the science that their discoveries led to; that is why they are important, and why historians study them. And the significance of their science changes with time, so it is inevitable that we regard it differently as we look back: With the discovery of the Aharonov–Bohm effect, the magnetic vector potential of James Clerk Maxwell and his Victorian contemporaries takes on a new meaning. In addition, many of our famous predecessors were cleverer and wiser than us; they left "time bombs," ignored for generations until, suddenly triggered by resonating with a contemporary preoccupation, they explode.

One such time bomb is Isaac Newton's query 3, which he posed[1] after decades of struggling to accommodate Grimaldi's observation of edge diffraction fringes in his ray theory of light: "Are not the Rays of Light, in passing by the edges and sides of Bodies, bent several times backwards and forwards, with a motion like that of an Eel? And do not the three Fringes of colour'd Light above-mention'd arise from three such bendings?" Now, three centuries later, and thanks to three insights, we can understand[2] that this apparently eccentric remark makes perfect sense.

The first insight was Sommerfeld's 1896 exact solution of Maxwell's equations for light diffracted by a conducting half plane.[3] The second insight was Braunbek and Laukien's 1952 calculation[4] exhibiting Newton's eel-like undulations by plotting the trajectories of the Poynting