Physics education research and student development

Thirty years ago, while teaching a physics class, I noticed that most of the students answered certain test questions incorrectly—in exactly the same way—because of a common misconception. I went back to my lecture notes and beefed them up, but I got the same results from the next class. Finally, I said the magic words, "This will be on the test; be sure you understand it." On my subsequent tests, students gave me the answer I wanted. But in the next semester, those same students had reverted to their original viewpoints. That behavior was pointed out in the Quick Study by Andrej Favia, Neil Comins, and David Batuski (PHYSICS TODAY, August 2016, page 74).

Suppose a problem involves a package being dropped from a moving aircraft, with the package being initially at rest relative to the plane. If the student draws a diagram with a straight down or triangular trajectory, the mathematics that follows is correct, but the answer is wrong. Knowing that the trajectory is parabolic is crucial to the correct solution.

Unknown to me, other faculty members in the US were noticing the same phenomenon and began making lists of misconceptions, which have been presented at meetings of the American Association of Physics Teachers and in online forums. Beginning in the 1990s, the Force Concept Inventory—a test of those misconceptions—was formed,[1] and more than 12 000 students were tested, both with and without reformed instruction—which involves active student engagement during lecture and laboratory in various tested forms.

The key to correcting common errors is eliciting the misconception in preliminary questioning, confronting it with contrary hard evidence, and then guiding students in the formation of a new understanding.

The method worked. Testing before and after its use revealed significant gains in busting misconceptions—reform teaching was *substantially* better.[1] The reform effort fostered the Physics Education Research (PER) Group at multiple physics departments in the US.

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Many converts came on board, but there were doubters. Academic freedom has allowed a mix of reform and nonreform classes to coexist in physics departments, and that coexistence has remained.

The optimal place to implement the new process is the laboratory. In traditional labs, students follow terse and often confusing cookbook instructions, have little understanding of what they are doing, and move one foot in front of the other. They then go home with reams of raw data in handwritten tables—to make graphs, draw conclusions, and answer final questions. Alone.

In the five venues where I have tried to reform the labs, only one department embraced the change. As I look back, the failure to adopt was related to the fact that faculty do not have academic freedom in laboratories; usually, the entire department uses the same materials. Diverse views about what are the crucial points cannot be accommodated easily. And so there develop factions, hard feelings, and sometimes sabotage of reform efforts.

To successfully implement laboratory reform, the entire department has to agree on several components:

- Eradicating misconceptions must be a major purpose of experiments. That includes guiding students to manipulate experiments and understand the measurement process, learn by inquiry, replicate important equations, and apply the scientific method.
- Following one's intuition about best teaching practices does not trump what extensive PER research has found to be most effective.
- Attending one conference does not make a faculty member a PER expert. Multiple techniques must be tested in the local academic culture.
- Sending students home with huge tables of data to be analyzed—the way I was taught—should be abandoned.

My preferred method for laboratory work is to quickly take all-encompassing data by computer acquisition, perform automatic graphing, and have a summative small-group-guided interpretation period during the lab time. In my view, a student should meet 90% of the lab goals while still in the lab, not in take-home work.

Not attaining department agreement on the above items leads to failure. Few physics departments in the US have implemented laboratory reform and maintained it over several years. The University of Colorado, Washington University, and Dickinson College have continually provided leadership in developing techniques and resources for improving student outcomes.

Reference

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Fracking and the future of fuels

The July 2016 issue of PHYSICS TODAY carries an article by Michael Marder, Tadeusz Patzek, and Scott Tinker entitled "Physics, fracking, fuel, and the future" (page 46). The article claims "to contend with the challenges of fueling modern society" and invites physicists to help. Unfortunately, although they describe fracking and its impact carefully, the authors don't mention the controversy now raging about wind, solar, and other alternative fuel technologies, including modern nuclear technology. If Marder and coauthors want to stimulate constructive progress for humanity, they should help readers to think about fuels that have real promise of outlasting oil and gas.

The article cannot be the end of the discussion. The world drastically needs to overhaul its energy production scheme to use truly sustainable, modern, and safe nuclear reactors, while utilizing the vast existing infrastructure of turbines and generators for electricity production. Despite media portrayals to the contrary, nuclear energy is the safest power system known to man.[1] In the late 1960s, the Sierra Club's motto was "Atoms, not dams," and Ansel Adams, who was on the club's board of directors for 37 years, said, "Nuclear energy is the only practical alternative that we have to destroying the environment with oil and coal."

Consider the following facts about molten-salt reactors (MSRs), which were demonstrated in 1965–70 at Oak Ridge National Laboratory.

- MSRs require no expensive containment since they operate close to atmospheric pressure.[2]
- MSRs can eliminate the need for Yucca Mountain storage by consuming existing nuclear wastes.
- MSRs consume close to 100% of their fuel, compared with 3% for older reactors with solid uranium fuel.
- Thorium fluoride molten fuel for MSRs is of no weapons value.
- Thorium fuel is more abundant and cheaper than uranium.

The time is now to replace the current infatuation with solar and wind, which are illusions at best. When the sun doesn't shine or the wind doesn't blow, the power generation stops, so they are not equal to the demand of modern society for energy availability 100% of the time. Germany is demonstrating that removal of nuclear energy in favor of wind and solar results in more carbon emissions, not less.[3] Nor is energy storage even close to meeting the need when those alternatives fail. For this nation and the world to succeed without drowning itself in a flood of carbon dioxide in the next few decades, we need to follow the advice of Glenn Seaborg in 1962:

> The overall objective of the [Atomic Energy] Commission's nuclear power program should be to foster and support the growing use of nuclear energy and . . . make possible the exploitation of the vast energy resources latent in the fertile materials, uranium-238 and thorium.[4]

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The article "Physics, fracking, fuel, and the future" had many crucial omissions and misleading statements and thus failed to give a clear idea of where we are and where we are headed with regard to fossil fuels in general, renewable energy, and energy technologies. For example, climate change, the main driver in the push to reduce fossil-fuel consumption, was not mentioned in the article.

Moreover, the authors do not seem to realize that the movement away from fossil fuels is already well under way. The Energiewende (Energy Transition), Germany's program to change to low-carbon, nonnuclear energy sources, is never mentioned, and that Germany, Spain, and Italy already obtain more than 20% of their electricity from renewable resources is ignored. The authors seem unaware of California's goal to generate, without nuclear power, 30% of its electricity from renewable resources by 2020 and 50% by 2030.

The authors attempt to discuss petroleum extraction modeling: Their figure 2 shows a plot of US crude-oil production and results from M. King Hubbert's model. Inexplicably, the strong decrease