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Diverse suggestions for improving physics teaching

Lauren Aguilar; Greg Walton; Carl Wieman

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time. After all, isn't practice how American students master the game of baseball, the piano, and the skills of speaking, reading, and writing? Isn't that also how Chinese, Korean, Indian, and Singaporean students master physics and mathematics? And isn't that the way we train our Physics Olympiad finalists (http://www.aapt.org/physicsteam/2015/program.cfm), who by the way, are consistently sons and daughters of the segment of the population represented in the article's photograph?

I hope we don't change our PhD programs to accommodate women and minorities—or, more broadly, non-Jewish and non-Asian Americans. Let me finish by paraphrasing Euclid's famous quip when Egyptian ruler Ptolemy I asked him if there was an easier way to learn geometry than by reading *The Elements*: There is no American road to physics and mathematics.

References

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■ **A major emphasis** in the article "Psychological insights for improved physics teaching" is success in diversity by having teachers understand "students' perspectives" or "mindsets." Diversity should not be denied, but it cannot and should not be created by decoding students' mindsets. Consider the authors' description: "the conventional, if erroneous, wisdom that the population can be divided into math-brained and non-math-brained people." It is wisdom, but it is not erroneous. We've all seen our children or other students who are one or the other.

A math-brained student who does not also possess a great spark of curiosity will not transform into a physicist, no matter how good the teacher is. If the curiosity is there, then for all but the brilliant ones, a lot of hard work lies ahead. I speak from my own experience of quitting physics three times at different levels but succeeding in the fourth attempt. Teachers can psychoanalyze their students' mindsets forever, or imagine some intervention, but that doesn't make them better teachers or produce more physicists.

For some, the curiosity required for physics was stimulated by the science fiction of the 1950s, *Star Trek* in the 1960s, and the US space program of the 1970s; that was before smartphones, video games, and the overdone special effects in science fiction movies today.

I submit that improvement in student success in physics will come not from analyses of diversity and mindset but from the inherent pleasure of mathematics for those so brained and, for all, the curiosity often stimulated in the labs—one place where a good teacher can make a difference.

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■ **In their article** Lauren Aguilar, Greg Walton, and Carl Wieman stress the importance of knowing the psychological mindset of minority physics students and using nuanced "psychological interventions" to shrink the academic gender and minority gaps. The authors provide many interesting examples of how well-meaning encouragement and feedback given to improve student success can, in fact, further widen those gaps.

Although I find most of what the authors describe compelling, I am disturbed by the data presented in figure 3a, which shows that "values-affirmation interventions" can considerably reduce the gender gap: They bring up the average exam scores of women and bring down the average exam scores of men. The error bars—representing the standard error—do not come close to overlapping between the control and intervention groups in either demographic. Thus the figure would suggest that while the intervention reduces the gender gap, it also reduces the success rate of the top physics students in a manner that is statistically significant.

I'm disturbed that the authors ignore a seemingly negative consequence of focusing more on shrinking the gap than on boosting overall performance. Perhaps such interventions are supplanting some of the time devoted to teaching physics skills, or perhaps they are sending other unintended messages to top students, who may themselves be an academically and culturally distinct minority. On the other hand, it is entirely possible that the error bars are large enough to obviate such a conclusion, and therefore all of the reported intervention gains are also insignificant.

In the end, we must ask an inconvenient question: Which is more valuable—training the best future physicists or equalizing success across gender and culture? I'm not sure I have a cogent answer.

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■ **Aguilar, Walton, and Wieman reply**: We appreciate the interest that our article generated. The example provided by Robert Megginson shows how difficult it is for even the most well meaning, such as the dean in his story, to recognize aspects of the classroom (or lab) that are important to those who come with different experiences and perspectives. That story emphasizes the need to turn to research, as we discussed in our article, rather than relying on one's own opinions and experiences to understand the perspectives of underrepresented groups and how those perspectives may affect the quality of their experience and success in educational settings.

When people enter physics environments, they want to know, "Is anyone like me here? Will people value and respect me here?" For women and ethnic-minority students these questions have a special resonance, so they notice cues, like the absence of women, that other people overlook. Research shows that changing how students interpret those cues so that women and minorities feel valued and respected can unleash their potential. Such interventions don't change the curriculum or the standards. They don't give some students a leg up over others. They level the playing field.

William DeBuvitz underscores the importance of cultural stereotypes about scientists who are represented as either "antisocial eccentrics" or "so bright that everything comes easily to them." As he says, such a representation turns students off. Indeed, the research we referenced shows that a fixed mindset that some people are intelligent and other people just aren't leads students to view effort negatively. If you have to work hard, it means you're not "smart." That mindset makes students less persistent, less resilient, and worse learners. We echo DeBuvitz's recommendation that physicists communicate the need for "real academic work" and the idea that "one doesn't have to be a genius to be successful."

In contrast, Peter Hansen asserts that there are indeed math-brained people and non-math-brained people. When we see some introductory students "get it" quickly and others struggle, it's easy to have such thoughts. But we don't typically see the history or opportunities for learning that may have led to those differences. Moreover, the beliefs and expectations that children get from their parents and teachers are well known to have a powerful impact on their behavior and success. The belief that a child is inherently poor at math is very likely to be a self-fulfilling prophecy. We discussed the extensive studies showing that when students learn to believe that working on challenging material helps the brain grow, their learning and performance in math and science improve, sometimes dramatically. The effects are often greatest for students with a history of underperformance.

Aaron Slepkov astutely notes in the value-affirmation intervention shown in our figure 3a and reference 11, there was a negative effect for men on one outcome (exam scores). Due to a lack of space, we were unable to include a discussion about what appears to be a statistical anomaly. That pattern did not replicate on other outcomes (Force and Motion Conceptual Evaluation scores, course grades) or on any outcome in a replication study.[1] That result is reassuring; nonetheless, it is essential to monitor effective interventions for potential adverse effects among subpopulations of students.

The lack of impact on males is consistent with the broader literature we listed on value-affirmation and other interventions that mitigate the threat associated with negative stereotypes—for example, social-belonging and wise-feedback interventions. Members of minority or at-risk groups in school settings generally show benefits from those interventions; members of majority groups are usually unaffected but in some cases also benefit. This is not surprising, as the interventions are carefully targeted to the specific barriers faced by students in settings where their group is underrepresented and faces negative stereotypes.

Sadri Hassani raises many points without supporting data; we disagree with most of them, and believe that many people would find them offensive. However, there is some truth to his claim that what matters ultimately is, "How much time are they willing—or forced—to spend, at an early age, practicing physics and the mathematics that goes with it?" There is no doubt that mastering complex material takes time. But what motivates a person to invest that time, to struggle through challenges? If a student has a fixed mindset of "I just can't get physics" or "Maybe people like me don't belong" then he or she is less likely to invest in the field. The purpose of remedying psychological barriers is to encourage students to invest in physics.

Where will growth in physics come from in the coming decades? The greatest opportunity for growth comes from groups that are underrepresented in the field, like women and minorities.

Our article discussed the barriers to success that well-qualified women and ethnic-minority students encounter in the physics classroom. The research we reviewed suggests that simple and low-cost exercises can make a significant difference in bringing these people into the field.

Reference

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Fusion breeding for sustainable carbon-free power

Any reasonable option for midcentury, sustainable, carbon-free power should be given serious attention. In an earlier letter to Physics Today (May 2012, page 12), I suggested one—fusion breeding—as a better option for the US fusion program. The June 2014 issue of the magazine had three articles on the dilemma: "Pulsed-power machine studies weapons, simulates stars" (page 24), "Turmoil at ITER continues" (page 26), and "Nuclear energy output slows as climate warms" (page 28). However, the problem is much worse than those articles imply. Two energy options that have received considerable attention—controlled fusion and "green energy" (solar photovoltaic, solar thermal, wind, and ethanol)—are currently encountering fierce headwinds.

Consider the following: The cost of ITER has grown considerably and its completion date has been dramatically extended. Tokamaks will probably never be economical stand-alone pure fusion reactors, but they could be fusion breeders. The National Ignition Facility has missed its gain milestone by about three orders of magnitude. And recently the US Congress has taken a hard and unsympathetic look at fusion.

Meanwhile, green energy is not living up to its promise. According to a speech by German vice chancellor Sigmar Gabriel to his nation's solar industry leaders in April 2014, the collapse of that country's green-energy infrastructure seems imminent, and Germany's use of soft coal has significantly increased, which in turn has raised greenhouse gas emissions and electricity prices. In fact, any computer search will show that coal use has greatly increased worldwide in the past decade.

Although there are no guarantees that pure fusion and green energy will continue to fail or that coal use will continue its rapid increase, most indications are discouraging. Hence it seems appropriate to pay more attention to another option for sustainable, carbon-free midcentury power: fusion breeding.

A fusion breeder can fuel many thermal nuclear reactors of equal power. It takes two fast-neutron fission reactors at maximum breeding rate to fuel a single thermal nuclear reactor. (A single fast neutron reactor, however, can be configured to burn the actinide waste products—principally plutonium—of many thermal nuclear reactors of equal power.)

Developing fusion breeding will take decades of dedicated effort, but it is much more achievable than pure fusion. In any case, fuel for fission reactors is currently available and will be for a few decades. The time to develop fusion breeding and the time to largely deplete conventional nuclear fuel could well match up. A review article[1] and a textbook chapter[2] offer more details regarding the plasma physics and nuclear aspects of fusion breeding. It might well be that fusion breeding could develop into a sustainable, carbon-free power source by midcentury.

References

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