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Diverse suggestions for improving physics teaching FREE

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distribution of the 353-GHz map. The BICEP2 and *Planck* teams are now working together to perform that correlation analysis, and they are also including new data from the Keck Array in the South Pole at 100 GHz and 150 GHz.

Several other experiments will also expand the observed frequency range and make measurements on different and broader regions of the sky. In particular, the Cosmology Large Angular Scale Surveyor experiment, scheduled to be deployed next year, will observe at 40, 90, 150, and 220 GHz and will separate polarization components in situ.[5] If there are indeed detectable cosmic *B* modes, they should be seen with similar amplitudes by those other experiments, not only on the BICEP2 patch of sky but everywhere else as well. Furthermore, a true inflationary gravitational-wave signal should exhibit additional hallmarks, such as a characteristic angular power spectrum and statistics.

Overall, the *B*-modes story demonstrates how progress in science is truly achieved. Rather than through a direct march to the truth, science advances in a zigzag path that involves many false starts, detours, and blind alleys. Crucially, the scientific method requires that theories should make falsifiable predictions that can be tested through subsequent experiments or observations. Science therefore allows for self-corrections. Still, there may be some lessons to be learned here about the importance of communicating exciting and promising new scientific results to the public in a way that stresses the process, the uncertainties involved in measurements and interpretation of data, and their possible implications.

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Letters

Diverse suggestions for improving physics teaching

The photograph in figure 1 of "Psychological insights for improved physics teaching" by Lauren Aguilar, Greg Walton, and Carl Wieman (PHYSICS TODAY, May 2014, page 43) showed a physics lecture with an audience that appeared to be almost all white males. The caption suggested that most readers might not see what a woman or member of a minority group would see in that audience. I can attest to what one female high school student saw in a strikingly similar situation.

About 20 years ago, I was conducting an on-reservation summer program for Native American students, which ended with a class visit to an off-reservation college. The engineering school had offered a tour, which the dean conducted himself. He showed us an engineering lab with about a dozen people working diligently, mentioned the investment in equipment that allowed such research, and asked if there were any questions.

One of the female students in my class raised her hand and asked, "Why aren't there any women in there?" Her question brought the dean up short, but he handled it honestly, confessing that she had seen something important that he had not and that he was embarrassed and chagrined. So the question "Is there anyone like me here?" in the photo's caption certainly does get asked.

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■ **The authors of** "Psychological insights for improved physics teaching" made some good points, but I think an equally important factor affecting classroom success is the image of scientists in popular culture. Scientists are generally shown as either antisocial eccentrics or brilliant adventurers. Who wouldn't like to lead the life of Indiana Jones, an exceptional archaeologist who somehow, in his exciting and adventurous life, took time out to do the dull work of actually studying his subject?

According to the popular stereotype, successful scientists are so bright that everything comes easily to them. The assumed corollary is damning: A student who doesn't understand something immediately will never be successful as a scientist.

Even the brilliant Richard Feynman, though, had to work hard in his field. Unfortunately, he never stressed that fact in his own books. I guess his editor felt that describing in detail all the time he spent on his work would make his books too dull for popular reading.

Although Indiana Jones is a purely fictional character, his image can still have a strong effect on young people. The message that science is easy (for geniuses) and exciting can be found everywhere, including in science-oriented television programs like *NOVA* and *Cosmos*, where only the results of learning are discussed, but never the hard work.

Perhaps it is time to show that real academic work is necessary and that one doesn't have to be a genius to be successful. A reasonable level of intelligence together with a willingness to work hard can lead to a satisfying career even if it doesn't lead to the Nobel Prize or a popular television program.

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■ **The insights** by Lauren Aguilar, Greg Walton, and Carl Wieman on how students perceive their classroom experience and on suggested interventions for improving physics teaching are indeed helpful in elementary and perhaps middle schools. By the time students reach high school and college levels, however, it is too late. Many students in my college freshman general-education physics course do not understand the concepts of multiplication and division and often mix them up even in obvious situations. Students with an unacceptably weak background in mathematics can require months of intervention to correct just the arithmetic difficulties—something that should have been done in elementary school and is clearly impossible in a one-semester university physics course.

What struck me most in the PHYSICS TODAY article was the caption for figure 1 on page 44. The photo was taken at a physics conference and drew attention to the absence of women and minority groups in the picture. What was not visible was that an ethnic head count of the audience in that or any other physics-related conference would reveal that it was mainly foreign physicists, second- or third-generation Eastern European Jewish immigrants, and Asian Americans. So beyond addressing the question of why women and minorities are underrepresented, we have to resolve the issue of the underrepresentation of all non-Jewish, non-Asian Americans.

The current American educational establishment is far more favorable to women and minority groups than was 19th-century Europe, so if Emmy Noether, Marie Curie, and Sofia Kovalevskaya could succeed there and then, any girl or minority should be able to succeed in 21st-century America. In my opinion, the underrepresentation in physics and mathematics is the outcome of the US way of life and its fascination with, and submission to, the youth culture, whose ultimate aspiration is to appear on *American Idol* or *The Voice*. That submission already has had a devastating impact on our undergraduate physics and mathematics.

During the unpopular Vietnam War, when the counterculture of the 1960s associated physics with the military–industrial complex, physics lost any trace of popularity among young people, and its affiliation with the difficult subject of mathematics only stoked its unpopularity. To woo young people, some physics educators came up with a way of making the subject "attractive." Radical conceptualism conquered undergraduate physics pedagogy, and mathematics, which ever since Galileo was the language of physics, was exiled. Equations gave way to colorful cartoons, and the conceptual "physics for . . ." courses mushroomed throughout the land.

What a far cry from the wisdom of the Committee of Ten, an 1890s group of educators who wanted to standardize the curriculum in US high schools. They wrote, "Every subject which is taught at all in a secondary school should be taught in the same way and to the same extent to every pupil so long as he pursues it, no matter what the probable destination of the pupil may be, or at what point his education is to cease."[1]

The 1960s also saw a dramatic increase in the application of psychology and cognitive science in mathematics and physics with the intention of improving teaching. Almost 30 years later, US 12th graders performed miserably in an international assessment of science and mathematics.[2] And almost 50 years later, we are still talking about "psychological insights for improved physics teaching" while the nation receives a failing report card for its 12th-grade performance in mathematics.[3]

The ultimate question of how students learn physics and mathematics is this: How much time are they willing—or forced—to spend, at an early age, practicing physics and the mathematics that goes with it? It is puzzling that such an obvious fact has eluded physics and mathematics educators for such a long

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.

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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