We need to rethink lower-division physics teaching

Over a 30-year teaching career, I have noticed some embarrassing gaps in basic physics understanding among faculty members and students. Those gaps, originating in the first-year calculus-based physics courses taken by science and engineering students, seem mainly due to choices of pedagogy and format made by lower-division textbook writers. When the writers were deciding how to write introductory textbooks, they understood almost nothing about human brain science or learning modalities. We need to take time now to reconsider those choices.

Introductory courses tend to teach from particular to general, which often means that instructors run out of time and general concepts are never presented. I believe the rationale for that choice was to retain weaker students by not overloading them. But the approach ignores the primacy effect: Social scientists have long known that people tend to remember information presented earlier better than that presented later. Students are therefore apt to lose the big, general picture.

Another problem is that textbooks and instructors cram too much information into introductory courses; they especially include new findings in an effort to provide exciting and relevant material. One motivation for the information overload is pressure from admissions departments and accreditation boards to finish a four-term course in three terms or less. Thus informative general introductions to and road maps of topics across chapters and semesters have been tossed under the bus.

An introductory course is the only opportunity many students have to compare subtopics and to gain a big-picture concept map of physics. Upper-division and graduate courses focus narrowly on specialized topics, and big-picture summative connections are rare. As a result, misconceptions about broad, basic concepts never get addressed and may remain once students have become professors.

The issue I see is with existing faculty misconceptions rather than with students. A self-sustaining feedback loop has been created: A student learns conditional and half-truths in lower-division courses and may not absorb the full truth in more advanced studies. That student later becomes a professor and is assigned to teach a lower-division course. The professor is presented with a supposedly authoritative, well-thought-out text and relapses to teaching the half-truths they were taught.

By perpetuating the cycle of misconceptions, we are letting our students down. Here are a few examples of ways in which introductory textbooks could change their presentations to help students build broad understanding and avoid misconceptions.

Rather than teaching Maxwell's equations in integral form, which hides some salient and important features, teachers should use differential form. It may be more challenging: Beginning students are far better at understanding and calculating with differentials than with integrals.

As a first example, introductory courses present Coulomb's law as the final truth even though it is not universally valid. I have always taught it from general to particular despite what appears in textbooks. Instead of the simplified version, I begin with

$$\vec{E} = \frac{q}{4\pi\varepsilon_0}\left[\frac{\vec{e}_{r'}}{r'^2} + \frac{r'}{c}\frac{d}{dt}\left(\frac{\vec{e}_{r'}}{r'^2}\right) + \frac{1}{c^2}\frac{d^2}{dt^2}\vec{e}_{r'}\right],$$

and I point out that for historical reasons and calculation difficulties, I will address the second and third terms through electric charge velocities and accelerations. I leave the details for higher-level courses.

I offer a second example: Instructors often use painfully anemic explanations when introducing waves. Simply put, waves have two basic properties: Their

speed is dependent on environmental factors, and they travel at that speed in all moving observer reference frames.

I use the Doppler effect to introduce true relativity of observer experience. When I hear and measure a frequency while observing a moving sound source, that perceived frequency depends on both my vector location relative to the source's velocity and the relative velocity between the transmitter and myself.

For the sake of clarity, it is okay to bring up information that will be covered in a future term. I tell my students that, in principle, sound and light behave in the same manner, with both subject to wave restrictions.

Then I introduce speeds for light and sound: $c_{\text{light}} = c$(electromagnetic vacuum properties) $= c(\varepsilon_0, \mu_0)$, $c_{\text{sound}} = c$(air properties) $= c(T, m_{\text{molecules}})$. For first-semester students who have not yet encountered them, ε_0 and μ_0 can be described as the strengths of the electric and magnetic forces. Students can go back to what they know about the Doppler effect to understand that the reference frame transformation function, $\Gamma(v)$, is a function of the relative frame velocity v. However, be-

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cause the wave speeds for both light and sound are independent of v and because $c = \lambda f$, the factor $\Gamma(v)$ must appear reciprocally in both the frequency and wavelength transformations.

Then, when the same issue arises in special relativity for light, the groundwork has been done and students don't experience culture shock or feel betrayed.

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Tito's interest in science

The feature article "Physics in the former Yugoslavia: From socialist dreams to capitalist realities" (PHYSICS TODAY, August 2019, page 30) mentioned the strong interest and encouragement the country's leader, Josip Broz Tito, gave to science in the then newly founded Federal People's Republic of Yugoslavia. I add one further account that shows his interest.

I was at the Princeton Plasma Physics Laboratory (PPPL) when Tito visited it in 1963 as part of his tour of the US. Why he chose to visit us was not clear to me at the time since the work at PPPL had, at best, only long-range applications to fusion power. However, I now see that it was a part of his general interest in both science and its applications in planning for the future of Yugoslavia. He was the only head of state to visit PPPL while I was there. I recall the event clearly because it was the first and only time I have ever shaken hands with such a notable.

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A scenario for getting rid of the bomb

Regarding Thomas Jonter's article "Getting rid of the Swedish bomb" (PHYSICS TODAY, September 2019, page 40), I have a comment. Everyone in the world who might be considering building or using the atomic bomb should have as required reading the novel titled *Alas, Babylon* (1959) by Pat Frank. Although the story is fictional, it is not too far from what the ugly truth would be if means of mass destruction, such as the bomb, were to be used as weapons of war.

The book clearly approximates what things would be like if an accident involving nuclear weapons should ever happen. The only solution would seem to be that all nations simultaneously agree to stop production of such weapons and dispose of any that they have. Otherwise, a freak accident like the one depicted in *Alas, Babylon* could become a terrible reality.

I am 90 years old and don't have too much time left, so perhaps I should not worry about such a situation. However, I do have family members who will be around for many more years. I can