Are Most People Too Dumb for Physics?

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In last month's issue of *TPT,* Michael Sobel[1] turns our attention to the increasing number and broader population of students taking physics courses and urges us to reconsider how to better cater to their needs. We applaud the author for focusing our attention on this important issue. However, we find his proposal for teaching physics to nonscience majors problematic.

Sobel argues that these students need not "do" physics because "they are not likely to face this kind of problem-solving challenge in their future." Sobel proposes a "middle way between the traditional physics course and the conceptual course" that "avoids the shallowness of conceptual physics, yet lies within the capability of the *average* student." This middle way "does not demand ingenuity," it "does not demand that the student put together two ideas that he has previously used separately," and "does not demand that the student be clever." Students "are not expected to figure out for themselves how to work [a] problem, how to convert from the words to [an] equation, how to go from diagrams to vector components, etc."

Instead, Sobel suggests that students should learn physics as historical narratives. Each semester, students would be presented with three or four physics "stories," each story being associated with one or more equations. For each story, a "student sees a certain problem done in class, then tries three or four examples of the same problem, with different numbers, at home, and later has to do one on the exam." Learning physics, the author argues, is becoming familiar with this computational process. Students, he concludes, "don't have to be clever; they just have to be industrious." We disagree, both about students and about learning physics.

Sobel's piece is of importance because many of his claims are frequently heard in informal contexts: between teachers in hallways or during departmental meetings. Although widespread, these claims have generally not appeared in the literature. We offer this response as a means to initiate a dialogue on how we engage with students in our physics courses.

We focus on three frequent claims that Sobel's "middle way" is based on:

Claim 1: Difficulty

Physics is too difficult for the "average" student.

Claim 2: Relevance

Nonscience students don't need to "do" physics because they "are not likely to face this kind of problem-solving challenge in their future."

Claim 3: Conceptual physics is shallow

Concepts are too easy and don't help students solve problems.

Just Too Difficult for "Average" Students

Sobel claims—as do many teachers—that physics is in a "special category of hard" and is usually taken only by a "certain sort of very bright student." After having spent numerous hours in class explaining and providing worked examples, teachers frequently emerge from grading a number of failing exam copies with the feeling that some students are just not smart enough or simply did not work sufficiently. We come

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to this conclusion by projecting ourselves into the past where more effort almost always led to better understanding. However, we know students are not miniature versions of ourselves. If they were, they would all become physics teachers!

This shifting the responsibility away from instructors onto students is quite problematic. Dykstra[2] explicitly warns against this common physics teacher conception as follows:

> "It is acknowledged that not all can receive the transmitted knowledge effectively. To account for this the construct, deserving, is applied. If one is deserving, then one can effectively receive the transmitted knowledge. To be deserving, one must first have the mental capacity [i.e., in Sobel's words 'a certain sort of very bright student'] and then one must work diligently enough [i.e., in Sobel's words, 'just needs to be industrious'] to be successful at 'getting' what has been transmitted or can be seen in nature."

The issue with arguments about ability, industriousness, or deserving nature of students is that they shift the focus away from what needs to be done to help students learn basic concepts and understand the nature of physics. The appealing—yet suspiciously conceited—notion that physics is only for smart or industrious people is in fact quite questionable. There are numerous examples showing how students from nonscience backgrounds learn important expert-like skills in modeling, conceptual framing, and problem solving.[3]

Relevance: What Is Education For?

The claim is, why burden nonscience students with problem solving if they will not face such challenges in the future? One reaction to this claim may be: What data support the notion that students will not face such challenges in the future? However, a broader issue should be addressed: What is meant by "problem solving?"

In cognitive science, problem solving has been defined as a process that minimizes the difference between a current state and a desired "goal" state.[4] Problem-solving processes differ across knowledge domains,[5] which has pushed researchers to focus on the study of domain-specific expertise.[6]

Granted, nonphysics majors need not achieve expertise in physics. However, one of the basic learning outcomes of a physics course is the ability to solve problems. Physics education researchers have tried not to conflate solving exercises (such as those found in end-of-chapter examples) with problem solving. As Korsunsky[7] notes : "Problem solving [is] commonly understood as the ability of individuals to apply their prior knowledge in new, somewhat unfamiliar, situations." This unfamiliar, novel aspect of problem solving is central because, as Martinez points out, "If we know exactly how to get from point A to point B, then reaching point B does not involve problem solving."[8] Furthermore, "by its very nature, problem solving involves error and uncertainty …. The possibilities of failure and of making less-than-optimal moves are inseparable from problem solving."[8]

Outside of their physics courses, students may not face the kind of challenge given by algorithmic computational procedures such as those found in end-of-chapter exercises. We fully agree that such exercises are of little value to students. Yet, the proposal to have students try "three or four examples of the same problem, with different numbers, at home, and later has to do one on the exam" hardly qualifies as problem solving. The only advantage provided by such tasks is that they are simpler to teach and to test than complex problem solving.[8] The late Arnold Arons had warned against "the widely prevalent illusion that students will master arts of thinking and reasoning as well as… concepts, principles, models and theories…through the doing of conventional end-of-chapter homework problems. This is demonstrably not the case."[9] The kind of task proposed by Sobel is more of an exercise than a genuine problem-solving activity and provides students with very little benefit. Clearly, this kind of task is no more likely to be encountered by students outside of their physics courses. Most concerning is that this kind of task provides students with a flawed expectation with respect to the nature of physics.[10] Which brings us to the central issue: What is education for? What do we expect students to learn from their physics course?

Most educators, regardless of the discipline, want their courses to have an effect that extends beyond their classroom and hence would prefer to educate broadly rather than train for specific tasks.[11,12] This ought to be particularly true for students taking courses out of their discipline such as nonscience majors taking physics. Much research has shown the problems associated with teaching through decontextualized situations that are not relevant to students' experiences out of school.[13] In physics, research on providing students with meaningful context-rich problem-solving activities shows that students better understand the basic concepts and the kinds of reasoning that are characteristic of our field.[14] That students would "not [be] expected to figure out for themselves how to work [a] problem, how to convert from the words to [an] equation, how to go from diagrams to vector components, etc." would contradict the findings showing that providing multiple representations in context-rich problems helps students learn basic concepts and solve traditional problems.[15,16]

In physics, there is a long tradition of modeling and explicitly teaching problem-solving skills. Students are encouraged not only to solve problems but reflect on the process.[17] This thinking about one's thinking, or metacognition,[18] whereby one monitors and reflects upon his or her thinking, is extremely helpful in learning science[19] and mathematics.[20] Furthermore, metacognition is also a common characteristic of expertise across domains.[11] Thus, reflecting on the thinking involved in context-rich problem solving develops metacognitive skills, which is one of the hallmarks of experts, regardless of their domain.

Conceptual Physics: Shallow or Deep?

We fully agree that physics concepts without any math yield an incomplete picture of physics. However, math without physics concepts is equally incomplete. Unfortunately, math with too few concepts is precisely what many students get out of their introductory physics courses.[21-23]

Ideas in physics (or in other disciplines) are not purely mathematical. Ideas can be represented mathematically as they can be represented in words, pictures, or graphs. In fact, the number of representations accessible to an individual is a measure of expertise. Ideally, students should be able to represent any idea through multiple representations, including mathematics.[16]

Math is an important tool, a shorthand that facilitates reasoning.[24] Yet, the claim is: "Math can be hard." Those who have taught algebra-based courses will acknowledge that physics is not necessarily easier when the math is taken out. Empirical findings support the counterintuitive notion that conceptual questions are in fact more difficult for students than formal mathematical solutions.[22,23] Yet, in team-taught classes or in multi-section courses with common exams, colleagues often object to conceptual questions in exams because they are "shallow" or "too easy." Furthermore, time spent on conceptual questions helps student not only get the basic concepts, but it also increases students' performance on traditional problem-solving tasks.[23,25] Hence, research findings argue against this notion of "shallowness" of concepts by showing that concepts provide a foundation from which students can construct flexible solutions to different problems.

In conclusion, while we concur that it is time for us to consider what, how, and who we are teaching, we disagree with most of Sobel's claims. We thank him for his article and welcome this opportunity for our community to collectively reflect on what students ought to learn from physics courses.

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