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APS News – The Back Page

The "Curse of Knowledge" or Why Intuition About Teaching Often Fails

By Carl Wieman

In the pages of the APS news and elsewhere there has been much discussion about the deficiencies of our science education system. Everyone from leaders of government, industry, and academia to concerned parents is pointing to the evidence and lamenting how these deficiencies hinder economic growth and the attainment of a scientifically literate citizenry capable of making wise informed decisions on important societal issues. Usually, such laments are accompanied with an opinion as to the source of the problem and how to solve it. One common claim is that higher education is failing because the faculty members in science care only about research and have little interest or concern with teaching. (Physics is often held out as a subject of particular criticism in this respect.)

I reject this claim. I have spoken with many physics faculty members throughout the world about teaching, and I can probably list on one hand the number who did not have a clear and sincere desire to have their students learn physics and appreciate its usefulness and inherent intellectual beauty. So how can one reconcile this observation with the compelling accumulation of physics education data showing most college students are not attaining these goals? (And if such education studies do not convince you, just ask a few non-physicists how they feel about their college physics classes!)

Here I would like to offer an explanation for this disparity between good intentions and bad results and, on this basis, suggest how to improve teaching and learning. The explanation arises from what has sometimes been called the "curse of knowledge" by educational psychologists. It is the idea that when you *know* something, it is extremely difficult to think about it from the perspective of someone who does *not* know it. There is a classic easily replicated demonstration of this provided by psychologist Elizabeth Newton.[1] She had subjects tap out the melodies of very familiar songs with their finger and predict what fraction of those songs will be recognized by a listener. "Tappers" typically overestimated the fraction recognized by a factor of 20! In a recent science education example of the same idea, we saw students express disbelief that anyone could hold a certain misconception, yet we had seen those same students actually express this very misconception themselves, just a few months earlier! I would argue that well intentioned physicists are achieving poor educational results because the "curse of knowledge" makes it very difficult for them to understand how physics is best learned by a novice student, or to accurately evaluate that learning.

Recent advances in brain imaging show us that this gap in understanding has quite basic origins.[2] The brains of novices in a subject are activated quite differently from experts when confronted with a problem. And as mastery is achieved, the brain literally changes; different links are formed and there are different activation patterns during problem solving.

This fundamental difference between the novice and expert brain explains many of the findings reported by those who study student learning of physics. Students can think about a topic in ways quite unimagined by the instructor, and so a lesson that is very carefully thought out and is beautifully clear and logical to experts may be interpreted totally differently (and incorrectly) by the student. Another example is that the standard lecture demonstration has been shown to have negligible impact on learning.[3, 4] Many teachers find this hard to believe because the demonstration attracts students' attention and usually demonstrates an important idea in a compelling fashion. However, the lack of learning makes sense when one realizes that research also shows that students often perceive both the intention of the lecture demonstration and what it shows very differently from the instructor.[4] My group routinely sees similar perceptual differences in our testing of educational interactive simulations.[5] When we have students try an untested simulation, they often literally see different things happening on the computer screen than do experts. As a result, the student can interpret what is shown very differently from what was intended, and learn incorrect ideas. Finally, studies reveal that the instructor's interpretation of the student's thinking based on their exam answers is frequently very different from the actual thinking.[6] In much of science instruction, it is almost as if the instructor and the student are speaking different languages but neither realizes it.

This mismatch between student and instructor perceptions can lead to even more disturbing results at another level – namely that of general beliefs about the nature of physics, how it is learned and used, and how physics knowledge is established. The University of Maryland physics education group and now my own group have studied such beliefs in students and how they are shaped by physics courses. We have consistently measured that such student beliefs, on average, become *less* like those of a scientist after completing typical introductory college physics courses.[7, 8] Put in the starkest terms-- our physics courses are actually teaching many students that physics knowledge is just the claim of an arbitrary authority, that physics does not apply to anything outside the classroom, and that physics problem solving is just about memorizing answers to irrelevant problems. Even more disturbing, we find that those students who are planning to become elementary school teachers have the most extreme of these novice-like beliefs. If one looks at the "anti-science" movement, one can see such beliefs inherent in much of what it represents. Of course, no teacher would intentionally be teaching such beliefs to their students, but the sobering fact is that the data indicates that this is what is actually happening in nearly all introductory physics courses.

This “curse of knowledge" means is that it is dangerous, and often profoundly incorrect to think about student learning based on what appears best to faculty members, as opposed to what has been verified with students. However, the former approach tends to dominate discussions on how to improve physics education. There are great debates in faculty meetings as to what order to present material, or different approaches for introducing quantum mechanics or other topics, all based on how the faculty now think about the subject. Evaluations of teaching are often based upon how a senior faculty member perceives the organization, complexity, and pace of a junior faculty member's lecture. In the pages of the APS news, this same expert-centered approach to assessing educational experiences has played out recently in the debate over the use of interactive simulations vs. hands-on labs.

It is even dangerous to decide on how one learns based upon your memory of learning physics many years ago. I was reminded of this recently while participating in a TA training workshop and reflecting on the differences between what the beginning graduate students (not yet physics experts but sophisticated current learners) felt was important for effective learning compared to what I often hear from senior faculty members. The beginning graduate students were asked to discuss and tabulate their "best and worst learning experiences." In their examples of best experiences, there was no mention of particular topics or how topics were organized or presented, except in the context of how the presentation was explicitly shaped to make the material interesting and accessible from their student perspective. While aspects of enthusiasm and interest of the instructor were mentioned, the students particularly focused on the instructor's interest in the students' learning, as evidenced by making efforts to find out what was being learned and providing individualized feedback and encouragement to support the student's learning. Other characteristics of instructors that are so often part of faculty discussions of teaching (such as personality or how easy or hard they made assignments or exams) were never mentioned. In fact, the most valuable learning experience for many of these grad students did not involve an instructor at all! A widely shared most valuable learning experience was "working with a motivated group" [of fellow students]. Finally, in many faculty discussions of good teaching one often hears it described as "an art form" that might be amenable to slight improvement by training and experience, but is largely an innate ability. In contrast, the characteristics of valuable learning experiences listed by these grad students were all straightforward things that any instructor could do, but many often do not.

Any reader who has gotten this far ought to be getting quite depressed. The data says our best intentions to teach well are failing, and many of one's ideas as to how to improve are suspect, because our brains are different from our students and so our intuition is flawed.

However, the situation is not nearly as dire as it might appear. The clever physics community has already found an approach for how make progress in areas where one's initial intuition is obviously flawed, e.g. figuring out the structure of atoms. That approach is to rely on careful objective experimental measurements and to use that data to develop new improved understanding and intuition. For teaching physics, this means looking at data on how people learn[9] and how students do and don't learn the various topics in physics. Of course an outstanding instructor gathers their own data by carefully and systematically probing the thinking of their students, but this is difficult and time consuming to do accurately. Relative to many other sciences, physics instructors are fortunate to have the benefit of a substantial body of education research on discipline specific topics,[10] as discussed on the Back Page previously by Noah Finkelstein. Guided by this literature, an instructor can bridge the perceptual gap and understand how their students are thinking, what are the common difficulties and misconceptions, and find rigorously tested effective ways to improve student learning and motivation. The literature also describes assessment methods to substantially help in efficiently gathering data on one's own students. This physics-like approach to the teaching and learning of physics has led to new insights and dramatic progress, such as the discovery of teaching methods that double or more the learning of concepts. By the way, the findings of this body of research on learning match well with the recollections of the TAs mentioned above as to the most important characteristics for effective learning.

In much the same way that physicists had to go through the wrenching process of replacing their classical-physics-based intuition with a new, more useful intuition about the quantum world, we need to make a similar step with regard to physics education. We must abandon the implicit assumption that all brains are the same and so passing along what is clear to us will be clear to the novice student, and if it fails, it is an indication that the students are simply incapable. We must instead come to recognize that mastery of a subject is much more a process of restructuring the brain than simply transferring of knowledge, and knowing a subject is profoundly different from knowing how that subject is best learned. The result will be greatly improved learning of physics. Knowledge becomes a curse only if one fails to recognize its limitations.

(References to the many studies mentioned here are not compatible with the Back Page format, but are posted at www.cwsei.ubc.ca/resources.)

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