Qualitative versus quantitative thinking: are we teaching the right thing?

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For the past eight years I have been teaching an introductory physics course for engineering and science concentrators at Harvard University. Teaching this class, which does not include any physics majors, is a challenging experience because the students take this course as a concentration requirement, not because of a genuine interest in physics. At the same time it can be a very rewarding experience when, at the end of the semester, students show much more appreciation for the subject matter.

I used to teach a fairly traditional course in an equally traditional lecture-type of presentation, enlivened by classroom demonstrations. I was generally satisfied with my teaching during these years — my students did well on what I considered pretty difficult problems and the feedback I received from them was positive.

About a year ago, however, I came across a series of articles by David Hestenes of Arizona State University,[1] which completely and permanently changed my views on teaching. In these articles Hestenes shows that students enter their first physics course possessing strong beliefs and intuitions about common physical phenomena. These notions are derived from personal experiences, and color students' interpretations of material presented in the introductory course. Instruction does very little to change these 'common-sense' beliefs.

For example, after a couple of months of physics instruction, all students will be able to recite Newton's third law — 'action is reaction' — and most of them can apply this law in problems. But a little probing beneath the surface quickly shows that the students lack any fundamental understanding of this law. Hestenes provides many examples in which the students are asked to compare the forces of different objects on one another. When asked, for instance, to compare the forces in a collision between a heavy truck and a light car, a large fraction of the class firmly believes the heavy truck exerts a larger force on the light car than vice versa. My first reaction was 'Not *my* students…'! I was intrigued, however, and to test my own students' conceptual understanding, I developed a computer program based on the tests developed by Hestenes.

The first warning came when I gave the test to my class and a student asked 'Professor Mazur, how should I answer these questions? According what you taught us, or by the way I *think* about these things?' While baffled, I did not get the message quite yet. The results of the test, however, where undeniably eye-opening: the students fared hardly better on the Hestenes test than on their midterm examination on rotational dynamics. Yet, I think the Hestenes test is *simple* — yes, probably too simple to be considered seriously for a test by many of my colleagues — while the material covered by the examination (rotational dynamics, moments of inertia) was, in my opinion, of far greater difficulty.

I spent many, many hours discussing the results of this test with my students one-on-one. The old feeling of satisfaction turned more and more into a feeling of sadness and frustration. How could these undoubtedly bright students, capable of solving complicated problems, fail on these ostensibly 'simple' questions?

On the following examinations I paired 'simple,' qualitative questions with more 'difficult,' quantitative problems on the same physical concept. Much to my surprise some 40% of the students did *better* on the quantitative problems than on the conceptual ones. Slowly the underlying problem revealed itself: many students concentrate on learning 'recipes', or 'problem solving strategies' as they are called in textbooks, without bothering to be attentive to the underlying concepts. Many pieces of the puzzle suddenly fell into place. The continuing requests by students to do more and more problems and less and less lecturing — doesn't the traditional lecture overemphasize problem-solving over conceptual understanding? The unexplained blunders I had seen from apparently 'bright' students — problem-solving strategies work on some, but surely not all problems. Students' frustration[2] with physics — how boring must physics be when it is reduced to a set of mechanical recipes without any apparent logic. And yes, Newton's third law is second nature to me — it's *obviously* right, but how do I convince my students? Certainly not by just reciting the law and then blindly using it in problems…

Just a year ago, I was entirely oblivious to this problem. I now wonder how I could be fooled into thinking I did a credible job teaching introductory. While several leading physicists have written on this problem,[3] I believe most instructors are still unaware of it. A first step in remedying this situation is to expose the problem in one's own class. The key, I believe, is to ask simple questions that focus on single concepts. The result is guaranteed to be an eye-opener even for seasoned teachers.

[1] Ibrahim Abou Halloun and David Hestenes, *Am. J. Phys*, 53, 1043 (1985); ibid. **53**, 1056 (1985); ibid. **55**, 455 (1987); Hestenes, David, *Am. J. Phys*, **55**, 440 (1987)

[2] Sheila Tobias, *They're Not Dumb, They're Different*, Research Corporation: Tuscon, AZ (1990)

[3] See for example: Arnold Arons, *A Guide to Introductory Physics Teaching*, John Wiley & Sons: New York, NY (1990); Richard P. Feynman, *The Feynman Lectures*, Vol. 1, (Addison Wesley, New York, NY, 1989) p. 1–1; Ken Wilson., *Phys. Today* **44:9** (1991) p. 71–73.

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