Tackling misconceptions in introductory physics using multimedia presentations

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Abstract: *All too often when researchers attempt to measure the learning that occurs in physics courses, they find that very little actually takes place. On a basic level, the reason for this difficulty is not hard to identify. Students come into physics classes with ideas about the subject matter that do not align with the scientific conceptions they are expected to master. More complicated, however, is determining how specifically these alternative conceptions undermine the teaching and learning process. We have studied multimedia learning involving different areas of physics with more than a thousand students over three years. We have interviewed students and collected quantitative data not only about learning, but also about student perceptions of it. Taken collectively, our results support the conclusion that misconceptions inflict their damage in two ways: they give students a false sense of knowing, limiting the mental effort they invest in learning; and they interfere with memories of recently learned scientific conceptions. Our experiments show, however, that exposing students to common misconceptions, even in non-interactive settings, can help them overcome these difficulties. We propose that misconception-based multimedia can alert students to key inconsistencies in their reasoning, and help tether their old ideas to new, scientifically accurate ones.*

Introduction

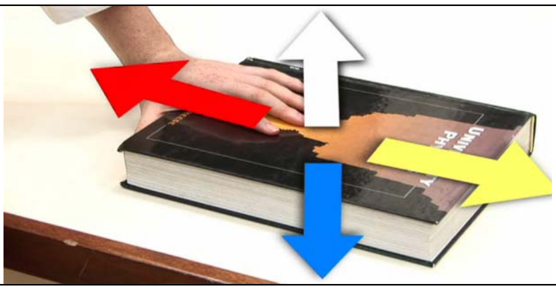
Imagine a first year student who has never taken physics before. She is quite bright, completed 4 unit mathematics in high school, and entered university with a UAI of 95. She is enrolled in *Fundamentals Physics* because this is the stream available to students with no formal prior physics experience. Early in her first year physics course, she logs onto a web site to participate in an educational experiment and receive credit towards an assignment. There she answers some basic conceptual physics questions like:

A book slides down a rough inclined plane with constant speed. While the book is sliding,

A. The force on the book down the ramp is greater than the frictional force up the ramp.
B. The force on the book down the ramp is less than the frictional force up the ramp.
C. The force on the book down the ramp is equal to the frictional force up the ramp.
D. The weight of the book is greater than the frictional force up the ramp.
E. The forces are irrelevant. The book moves downwards because of its natural tendency to be at rest on the surface of the Earth.

Her answer to this question is A because she reasons that the force down the ramp must be slightly greater than the frictional force, enabling it to move. She is also asked to rate how confident she is in her answer on a seven-point Likert scale. She chooses a five because she believes she’s right but can’t be absolutely certain. After completing the pre-test, she is shown a short, seven minute long video, which explains Newton’s first and second laws with the use of animations and live action demonstrations. An example with a book pushed across a table at constant speed is shown below.

After watching this video, the student answers the same questions as before. When she comes to the book question, she again answers A despite what was shown in the video. Furthermore, she increases her confidence rating to a six because she believes she better understands the concepts after watching the video. What are we to conclude about this student? Was the explanation not clear enough? Was she perhaps just not paying attention? Is the question tricky? Does this student not have what it takes to learn physics?



Four forces are acting on the book – there's the force of my hand, the force of gravity downward, the force from the table upward that balances the gravitational force, and friction backwards.

When the book is moving at constant velocity, I know that the force from my hand pushing the book forward is exactly equal to the force of friction from the table backwards on the book. The unbalanced force is zero and so the acceleration is zero – the book moves with constant speed.

Unfortunately in introductory physics education this scenario is common. And all too often it seems that students don't 'get' it the first time, become discouraged, and see physics as exceedingly difficult.

Diagnosing the problem

Similar observations have been made of students learning physics over the past three decades (diSessa 1982, McClosky 1983, Halloun and Hestenes 1985, McDermott 1991, Hestenes, Wells and Swackhammer 1992, Hake 1998). No matter how clearly articulated the scientific conceptions have been, few students have been able to master them. The reason for this difficulty is that students have interactions with the world, which they interpret in their own unique ways long before they enter a physics classroom. It seems these older ideas inhibit the understanding of new scientific concepts. Exactly how they do this, however, has been a topic of debate.

Some researchers characterise learners' naïve views as coherent and theoretical (Carey 1986, Vosniadou 1994). Observed commonalities between misconceptions and old scientific theories support this view. Others believe that students' conceptions are not very systematic at all; rather, they are composed of fragments of knowledge, which are cobbled together to form explanations when the need arises (diSessa 1982, Smith, diSessa and Roschelle 1993, diSessa 2006). The context dependence of student responses and the gradual nature of learning scientific conceptions are in line with this interpretation. Still a third view contends that it is not the structured or fragmented nature of students' ideas that is important, but the way in which these ideas are categorized ontologically (Chi, Slotta and De Leeuw 1994).

In our research, we have addressed the pragmatic issue of how to design linear multimedia so that it promotes conceptual learning. However, our data in conjunction with research from cognitive science and psychology allow us to comment on the specific ways in which misconceptions impact on learning.

Method

Common to all of our studies are two multimedia treatments we created using commercially available video equipment and *Flash* animation software. One, called The Exposition, consists of a lecturestyle presentation of correct physics information with accompanying diagrams, demonstrations and animations; the other, called The Dialogue, contains a scripted dialogue between a student and a tutor, involving common alternative conceptions. We first investigated these treatments in 2005 in the context of quantum tunneling (Muller, Sharma, Eklund and Reimann 2007), but in 2006 and 2007 we applied the same methods with Newtonian mechanics (Muller, Bewes, Sharma and Reimann OnlineEarly). It would be fairly straightforward to generalize the techniques to other subject areas but this has not been done yet. Multimedia was trialed online with students from the three introductory physics streams: Fundamentals, Regular, and Advanced.

In the mechanics studies, we investigated three additional treatments: the Refutation, identical in content to the Dialogue but narrated by a single speaker; the Extended Exposition, similar to the Exposition but with additional interesting information; and the Worked Examples treatment, again similar to the Exposition but with worked solutions to numerical problems. In the 2007 mechanics study, we also asked students to rate how much mental effort they invested while watching the multimedia on a nine-point Likert scale. This technique has been validated in many previous studies (Paas, Tuovinen, Tabbers and Van Gerven 2003).

Our results show that only the inclusion of misconceptions in multimedia seems to improve student learning, producing gains between half and one full standard deviation greater than the Exposition treatment. These gains were measured using pre- and post-testing with validated conceptual inventory questions from the Force and Motion Conceptual Evaluation (Thornton and Sokoloff 1998) and the Force Concept Inventory (Hestenes, Wells and Swackhamer 1992). Results also indicate that students invest more mental effort in watching misconception-based treatments. Interestingly, increases in student confidence do not reflect their increase in understanding. For example, in the 2006 mechanics study, students in all multimedia treatments raised their confidence ratings on average between 0.6 and 0.7 points on the seven-point Likert scale, as shown in Figure 1. Differences between the treatments were not statistically significant, even though learning gains for Dialogue and Refutation students were on average twice those of Exposition and Extended Exposition students.

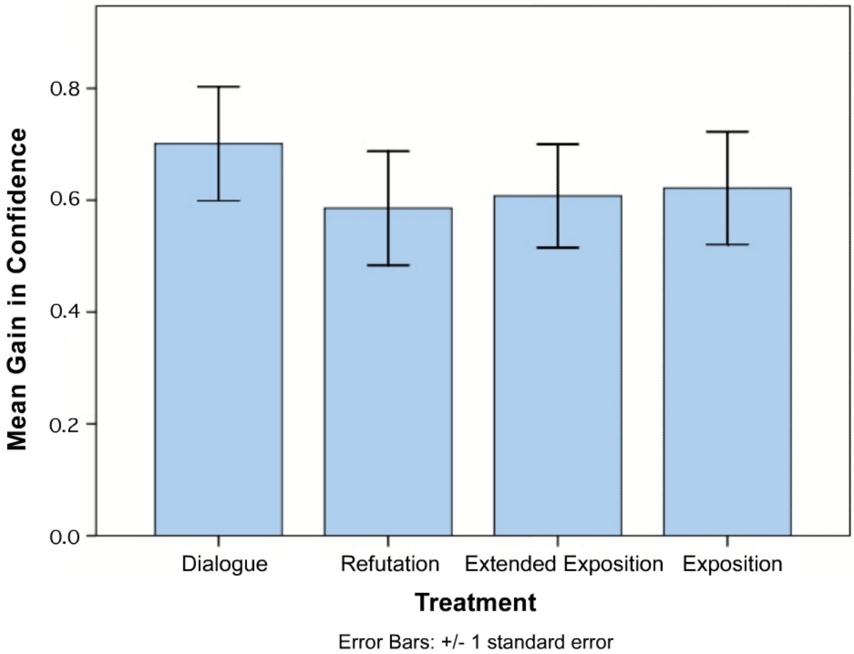


Figure 1. Students' confidence scores increased by the same amount regardless of which treatment they watched and regardless of how much learning actually occurred

Metacognitive impairment

These findings suggest that one of the ways in which misconceptions inhibit learning is by hindering the learner's ability to evaluate the presented information in light of his or her prior knowledge. This can be viewed as a kind of metacognitive impairment, metacognition being a learner's thinking about his or her own thought processes. A colleague working with the confidence data and the psychological constructs of over- and under-confidence (e.g. Kleitman and Stankov 2001) described the students in the above study as supremely overconfident. Furthermore, he concluded that Advanced students displayed much less over-confidence than the poorer performing Fundamentals. The general implication for such a finding would be that the Fundamentals require more training in metacognitive strategies and evaluating their knowledge structures.

We believe this view flips the problem on its head, but it is instructive when envisioning the effects of alternative conceptions. The problem is flipped on its head because, based on their high school results, we do not believe Fundamentals students are inherently less effective at executing metacognitive strategies than Advanced students. If, for example, their ability to judge the extent or correctness of their understandings in a domain area apart from physics were evaluated, we think they would perform equally well as the Advanced students. Their deficiency lies not in the knowledge evaluation process but in the knowledge with which they are evaluating. It is useful, though, to consider this phenomenon as though it *were* a metacognitive impairment. Students with alternative conceptions view the multimedia in the same way as they would if they had no way of evaluating whether the presented information matched or differed from their prior knowledge.

A key feature of this description of learning is that at no time is the learner aware that what he or she is perceiving is at odds with what is being presented. The words are familiar as are the situations discussed. The sentences used to describe the phenomena are not long or convoluted, nor does the presenter seem to struggle with making the concepts plain. And, importantly, the learner believes she already knows the general idea. Therefore meticulous attention is not paid to every detail of the multimedia presentation and mental effort is not invested in learning.

This explains why students in the Fundamentals and Regular streams reported high levels of confidence on the pre-test, even when answering less than 50% of questions correctly. It also accounts for the similar gains in confidence that were observed across all treatments, regardless of whether much learning occurred or not. Furthermore, it helps understand why students who viewed a non-misconception-based multimedia treatment invested less mental effort than their peers who viewed the Dialogue or Refutation.

Constructing on quicksand

The other way in which misconceptions appear to inhibit learning is through the phenomenon of proactive interference, a construct from cognitive science which has rarely been considered in educational studies. Proactive interference is said to occur when previously learned schemas inhibit the learning of new knowledge or skills (Eysenck and Keane 2005). One of the authors (DAM) is all too familiar with the phenomenon of proactive interference. Having moved to Australia from Canada, he finds a number of tasks difficult to accomplish because of this interference. In Canada, light switches are turned on by flicking them up rather than down. And some of the controls in cars are on opposite sides, leading to many humorous occasions during which the windshield wipers are activated instead of the indicator. Of course many people recognise the danger in driving on the other side of the road, but few consider the perils of walking on the right side of a footpath.

Proactive interference means that if any part of the presentation were perceived correctly, even though it conflicted with a student's prior knowledge, it would probably not make a lasting change to the student's long-term memory. Once attention was directed to a new concept, the recently perceived idea would be subject to proactive interference. That is, if the student tried to access this conception again, he would be much more likely to activate the older, more robust, alternative conception that the newly perceived scientific idea. Kane and Engle (2000) showed that learners with high attentional capacity were better at avoiding proactive interference than those with low attentional capacity. However, once an additional, unrelated task was performed by the high capacity learners, their performance was no better than the low attention group. This suggests another reason why investment of mental effort is vital to learning when misconceptions are involved – it helps reduce the interference of previously held beliefs.

Imagine the processes that must occur when trying to unlearn a misconception. First, when unfamiliar ideas are presented to a learner, he has difficulty interpreting them in light of his misconception schemas. This arguably demands more mental effort than if the learner had no prior knowledge on the subject at all. If he is capable of accommodating this new idea, he will then be faced with additional ideas that build upon this one. However, when he goes back to retrieve this idea from long-term memory, it may suffer interference due to the old conception. As Baddeley (1997) points out, older ideas seem to have greater robustness than newer ones. The process of learning a new conception is therefore like trying to understand little pieces of incomprehensible new knowledge while preconceptions acts like a schema quicksand, swallowing up newly learned ideas as the learner turns his attention to the next construct.

This explains why, following the multimedia presentation, students reported that their preconceptions were presented in the multimedia. Those aspects of the presentation that agreed with their prior knowledge, for example the idea that the force from the hand is greater than the force of friction initially to accelerate the book, were correctly recalled and even extended beyond the context in which they are valid (in this case, to include the movement of the book at constant velocity).

Towards a cure

Our research has confirmed many of the findings of previous studies that demonstrate the debilitating effects of misconceptions, but it also suggests a way forward. Treatments like the Dialogue and the Refutation dramatically increased student learning gains even though the format of instruction was the same, and changes in content were relatively minor.

One reason for the effectiveness of the Dialogue and Refutation is that they overcome metacognitive impairment. By presenting both the misconception and the scientifically accurate view, the student is made to consider two interpretations of the same phenomenon. This raises the average mental effort invested in the treatment and can lead the student to dissatisfaction with his or her current mental models. According to Posner, Strike, Hewson and Gertzog (1982) this is the first step towards conceptual change.

The other benefit of the Refutation and Dialogue relates to the way in which they provide a pathway from the alternative conception to the scientifically correct idea. In the Dialogue, for example, misconceptions are presented as the genuine views of one of the participants. Through Socratic discussion (Hake 1992), the reasoning is made explicit why the alternative idea in insufficient, and how it ties in to the scientific conception.

Misconception-based multimedia are, of course, not the whole answer to conceptual change. Peer Instruction (Mazur 1997), Interactive Lecture Demonstrations (Thornton and Sokoloff 1998), Tutorials in Introductory Physics (McDermott and Shaffer 2001), and Workshop Tutorials (Sharma, Mendez and O’Byrne 2005) have all been shown to dramatically improve student learning. Multimedia may, however, provide an inexpensive, supplementary method of facilitating conceptual change. Research investigating improvements to multimedia design (e.g. Mayer 2005) may also provide insights into the teaching and learning process and its challenges.

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