Can students learn effective learning and problem solving techniques in large introductory science courses?

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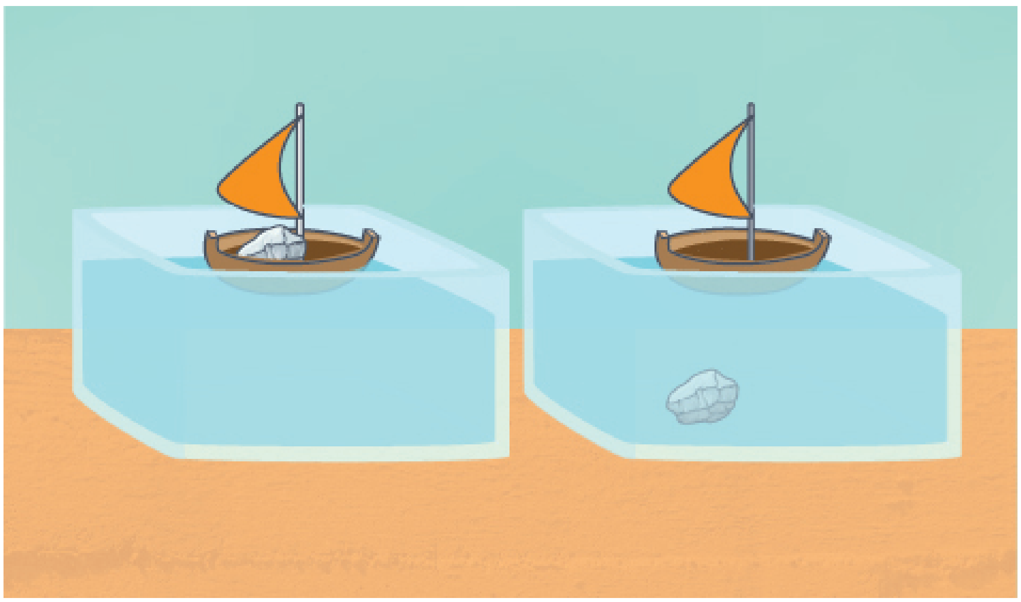

Q: If a stone aboard a boat is dropped in the water, does the level of the water rise, sink, or stay the same? An innovative physics course at Washington University coaxes students to reason their way through problems like this one instead of memorizing the answers. A: When the stone is in the boat it is displacing an equivalent mass of water. When the stone is thrown over the side it is displacing it's own volume in water. So which of these is greater? The stone must be more dense than water because it sinks. So the volume of water equivalent to the mass of the stone is greater than the volume of the stone. Less water is displaced after the stone is thrown overboard, and the water level goes down. Credit: Monica Duwel

In the past 10 years an active-learning course, called Active Physics, has gradually displaced lecture-based introductory course in physics at Washington University in St. Louis. But are active-learning techniques effective when they are scaled up to large classes? A comprehensive three-year evaluation suggests that Active Physics consistently produces more proficient students with better attitudes toward learning than the lecture courses it is replacing.

"Physics summer work, please help!!!," a post on Yahoo! Answers begins. "I cant figure out how to do this anywhere!!! Best answer awarded? Need help immediately!!!!!."

Most of the science and math queries on Yahoo! Answers resemble this one, although some are less hysterical. But they all make people who love science and teaching science cringe. It's not that they think the students are "cheating" by trying to google the answer, but rather that they know students who ask this kind of question are learning nothing and probably confirming a secret conviction that they're bad at science.

The Yahoo! Answers attitude is one of the toughest obstacles science teachers face. It tends to gather speed in high school when students are often defined as smart if they get the right answer quickly—by any means possible. In many cases, the last chance educators have to rescue students is an introductory science class in college.

Unfortunately these are often large lecture classes and research consistently shows traditional lecture courses drive steep attitudinal declines toward learning and problem solving in the sciences.

A three-year evaluation of an innovative course at Washington University in St. Louis that incorporates active-learning techniques but is still taught to large classes suggests the attitudinal decline is not inevitable.

The results of the evaluation, published in July 2, 2014, issue of *Physical Review Special Topics*, show that Active Physics has the expected benefits in conceptual learning and retains some, although not all, of the attitudinal benefits of small, inquiry-based courses.

Although the results were mixed, Active Physics consistently outperformed traditional lecture courses in conceptual learning and in attitudes toward learning and problem solving, said Regina Frey, the Moog professor of STEM (science, technology, engineering and math) education in chemistry who co-led the evaluation team.

"What's more, she said, Active Physics eliminates what is typically a big gender gap in attitudinal declines in traditional introductory courses. Women's attitudinal scores still decline in Active Physics, but much less than they do in traditional lecture courses.

The bottom line is that active learning works for large classes. "People like to say, "Well, of course you can implement active learning if you have classes of 40 or 50 or a skilled instructor," Frey said. "But they're skeptical that it will work in larger classes. What the evaluation showed is that the gains hold in large classes taught by many instructors over a number of years—if the curriculum is implemented properly.

Getting students off the mental couch

Washington University in St. Louis physics professor Tom Bernatowicz first introduced the Active Physics curriculum to a large introductory class in physics in 2004. Over the next 10 years other physics faculty began to teach Active Physics to equally large classes, and it gradually displaced the sections of the lecture-based introductory course.

Active Physics, a course based on the textbook Six Ideas That Shaped Physics by Thomas A. Moore of Pomona College, has its roots in the

1980s when educators, dissatisfied with lecture courses, became interested models of instruction that require students to take more responsibility for their own learning. Or as Moore puts it, "Physics is not a collection of facts to absorb, but rather a set of thinking skills requiring practice to master."

Every aspect of Active Physics is designed to nudge students to be more engaged in learning and to think more and memorize less. For example, both the Active Physics and the lecture sections of introductory physics include a demonstration of Archimedes principle (see illustration).

Students in the Active Physics class discuss what they think will happen before the demonstration, make a prediction and explain their reasoning to the class. Only once they have a stake in the outcome is the demonstration run. In the traditional lecture class, on the other hand, the instructor performs the demonstration without preamble, explaining the result.

Active Physics homework, homework revision and in-class problems are similarly designed to nudge students to dig into the physics instead of letting it wash over them. and to encourage them to try exploratory rather than rote learning. (For more about this course, see "Physics according to Bernatowicz.")

Losing the attitude

But nobody really knew whether Active Physics achieved the benefits of inquiry or active learning courses taught to much smaller classes.

By fortunate chance the provost's office at Washington University had recently funded a new center called CIRCLE (the Center of Innovation Research on Cognition, Learning and Education) and circle co-directors Regina F. Frey and Mark A. McDaniel teamed up with K. Mairin Hynes and other physics faculty to evaluate Active Physics. This evaluation compared the outcomes of students enrolled in Active Physics and the traditional lecture courses in the years 2009-2010, 2010-2011 and 2011-2012.

To assess how the courses changed attitudes, all of the students completed a 42-item questionnaire called CLASS (Colorado learning attitudes about science survey) that asks students to agree or disagree with statements about their attitudes toward physics and learning about physics.

The CLASS statements can be parsed in different ways to capture different aspects of student learning. The CIRCLE team defined two additional subsets of the statements that captured whether the students' learning approach was rote or conceptual and whether their problem-solving approach was algorithmic or concept based.

Students were asked, for example, whether they agreed or disagreed with the following CLASS statement:

"I do not spend more than five minutes stuck on a physics problem before giving up and seeking help from someone else."

"This statement is included," Frey said, "because many students coming out of high school believe that physics, and to some extent chemistry, is all math, and they have learned to do the problems by rote. That is, if the problem is very similar to ones they've seen before, they can use the procedure they're learned. But if it is superficially different, they can't see the underlying concept, and therefore cannot solve it. Because they think they should be able to look at a problem and solve it right away, they get frustrated."

Another CLASS statement that is equally revealing:

"In doing a physics problem if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem."

"They really work on this misconception in Active Physics," Frey said. "The students must estimate the answer before they solve the problem, and once they solve the problem they must say whether their answer is reasonable or not and why."

"Some students are naturally active learners," Frey said, "but many are not. So it is our job to teach them how to teach themselves rather than wait to be taught."

"If we want graduates who can really problem solve, innovate, be creative and lead, we have to teach students to be active learners. It's that active learning and complex problem solving we're trying to bring back into introductory courses using techniques such as active learning," Frey said.

Provided by Washington University in St. Louis