



## Spare me the lecture

US research universities, with their enormous classes, have a poor reputation for teaching science. Experts agree that a shake-up is needed, but which strategies work best? Kendall Powell goes back to school.

**R**ichard McCray says he feels like Oprah Winfrey, running up and down the lecture hall with a microphone, mediating student discussion. A professor at the University of Colorado at Boulder, McCray began turning his introductory astronomy course inside out three years ago.

Rather than lecturing to 200-plus students at a time, McCray divides them into 'cooperative learning teams' of about a dozen people, throws problems at them over the Internet, and then uses the lecture hall to discuss their various solutions. He did not innovate for the sake of it — he was deeply worried about the poor teaching performance of America's leading research universities. "We're losing talented people; we're driving students away," he says. "They don't like these large lecture courses."

Although educational institutions in many countries are struggling with similar issues, US research universities face a particularly tough problem in matching their specialist interests to the demands of society. A typical introductory science class consists of

a couple of hundred students, most of whom have no plans to continue with the subject, nor a great deal of prior knowledge. But in a world that increasingly depends on science and technology, it is more important than ever that these students learn the scientific basics. And that makes McCray's bleak assessment of the teaching failure of US research universities a matter of genuine social concern.

Some science professors are now trying to put new spins on their old curricula — using interactive computer technology, for instance, and employing various tactics to get students to discuss their ideas. Others, with an eye on the future, are trying to turn today's science undergraduates into tomorrow's high-school teachers (see 'Those who teach, learn, overleaf'). And a handful of educational innovators are applying the scientific method to their teaching experiments, testing new methods to determine whether they bring about improvements in learning.

Transforming the traditional learning environment is tough, particularly in a system where teaching excellence is not generally

rewarded with career advancement. What's more, some education experts argue that the scientists who are now developing an interest in the subject are ignoring prior research, and are in danger of reinventing the wheel.

But everyone agrees that the standard 'lecture-then-test' format is failing — particularly where lectures are delivered to huge numbers of students at a time. Evidence of this failure is provided by assessments such as the Force Concept Inventory (FCI), a multiple-choice test designed to examine students' understanding of Newton's laws of mechanics. Developed around a decade ago by David Hestenes, a physicist turned education researcher at Arizona State University in Tempe, the FCI has changed some researchers' opinions of their teaching techniques. When he first heard about the FCI, applied physicist Eric Mazur of Harvard University in Cambridge, Massachusetts, assumed that his élite students would perform perfectly well in the traditional lecture setting. So when they received an average FCI score of 70, where 80 is considered a pass, he got "a slap in the face".

As the number of students in each class is unlikely to fall any time soon, thinking of a way to make a 200-person course seem more student-centred tops the list of desired reforms. The solution advocated by McCray, who chairs the US National Research Council's Committee on Undergraduate Science Education, is to ask small groups of students to work on problems together. In the lecture theatre, he calls on each team to read its answer aloud so that the entire class can discuss it. In addition to these *Oprah*-style debates, McCray's classes sometimes resemble the 'ask the audience' segment of television's *Who Wants to be a Millionaire?* Class members have electronic clickers so that McCray can take a problem that has stumped many teams, turn it into a multiple-choice question, and ask everyone to vote on it. This instant feedback allows him to see if a common misconception has tripped up his students — and if so, to dispel it rapidly.

### Stretching exercise

Not all students enjoy the 'show' — many complain about the lack of a lecture and almost all find themselves outside their comfort zone. "I hated McCray's class when it first started," says Awwad AlWassem, now a fourth-year journalism student at Boulder. But he says that he appreciated the experience of working with classmates in a mock professional setting. He also says that he remembers more from the astronomy course than from other, lecture-based courses: "When someone tells you directions, it's not the same as if you've driven it already."

Mazur now uses similar methods to McCray's. "I did it out of total despair," he recalls. "I felt that nobody had understood what I had just taught." As an alternative to

lectures, he tried asking students to interrogate each other. Impressed with the results, he went on to base classes around such peer instruction, where students struggle with a problem, predict the answer, and then try to convince their neighbour of their argument (C. H. Crouch and E. Mazur *Am. J. Phys.* **69**, 970–977; 2001). Mazur also designed ConceptTests, sets of qualitative exam questions that rely on understanding a concept rather than simply using physical formulae. His methods have been adopted by physics teachers around the United States and have also been adapted for chemistry, astronomy, geology and mathematics courses.

Another innovation involves the use of information technology, which frees up more time for interactive discussions. Many instructors now combine texts and lecture notes into a single online hypertext document, often with animated illustrations and links out for more information. Once this basic instruction has been moved online, class time can be devoted to questions and discussion — in many cases using voting by electronic clickers, as favoured by McCray.

Online teaching tools can also go beyond lecture notes. When Carl Wieman, a physicist at the University of Colorado at Boulder, shared the 2001 Nobel Prize in Physics for his work on ultracold atoms, he decided to channel some of the prize money into his Physics Education Technology project. Wieman devised simple lab exercises, which programmers turned into software designed to help students visualize what would otherwise be abstract concepts. One of the programs shows the build-up of static electricity when students rub the foot of dancer 'John Travoltage' across a carpet. Another gets

students to build a circuit using a battery, switch, lightbulb and resistors. When the switch is thrown, the program illustrates the flow of electrons. "These allow students to visualize concepts in the same way that a trained physicist does," Wieman says.

### Lecture lag

Although many physics instructors were initially sceptical of the new techniques, there is evidence that they work. Wieman says that test scores have gone up by an average of two grades since he introduced his computer aids. And a survey that tested more than 6,000 students with the FCI at several higher-education institutions showed that straight lectures — whether boring or entertaining — proved significantly less effective than more interactive courses (R. R. Hake *Am. J. Phys.* **66**, 64–74; 1998). Other factors, such as class size and student preparedness, had little or no influence. Such results have spread like wildfire among physics departments concerned with improving teaching, says Mazur.

Next, say experts, studies need to be done to compare different types of interactive teaching. Daniel MacIsaac, a science education researcher at Buffalo State College in upstate New York, has developed a tool that may help with this. The Reformed Teaching Observation Protocol is a 25-question survey that is filled in by teachers observing science or maths classes. The resulting score is a rank, from 0 to 100, of the basic effectiveness of the innovations in promoting learning. Tests such as the FCI can then be used to see whether specific concepts are getting through to the students.

Tools similar to the FCI are also proving the worth of alternative teaching techniques in other areas of science. Mike Zeilik of the University of New Mexico in Albuquerque has developed the Astronomy Diagnostic Test (ADT). He found that women score more poorly on the ADT than men when taught in traditional lectures. But Zeilik says that when he replaced lectures with an interactive course in which students constructed 'concept maps' — diagrams linking key ideas into their proper relationships — the gender gap was closed, and both men and women did better overall. In unpublished work, MacIsaac has also shown that he can close gender and minority gaps on the FCI by using 'whiteboarding', in which students sketch out problems and present them to the class on shared whiteboards.

Another new test — the Biology Concept Inventories (BCI) — could also shake up biology professors in the same way that the FCI and ADT prodded physicists and astronomers from their complacency. "You can't fool yourself that because you lectured, it was learned," says Michael Klymkowsky, a developmental biologist at the University of Colorado at Boulder. To create the BCI, Klymkowsky and his Colorado colleagues survey professors in a given discipline to find out which key ideas should be covered. The next step is to interview



**Well rounded:** Daniel MacIsaac (centre) encourages students to form interactive discussion groups.

D. MACISAAC/B. AHERN/AZTEC 2002

students to find out what misconceptions they have about these topics. These are then used to form alternatives to the correct answer on the final, multiple-choice test. Ultimately, the researchers hope to create a tool that covers the whole of biology — however daunting that may sound. “I’ve bitten off 400 times more than I can chew,” jokes Klymkowsky.

For those who have been studying science education for many years, the influx of high-profile scientists is good news. “Welcome aboard! I want them all,” enthuses Diane Ebert-May, a plant ecologist at Michigan State University in East Lansing who has been working on biology education since 1987. But there is also concern that newcomers are ignoring existing knowledge and expertise or, worse still, being unscientific. “You have to think hard about your question and research design,” says Ebert-May. An education-research question poses greater challenges than an investigator’s own disciplinary research, she says, because it uses human subjects and few controls, and deals with the slippery data of learning.

### Prior knowledge

“If I were going into condensed-matter physics, I would certainly feel obligated to find out what people in that field already know, read the literature, and see what experiments have already been done,” says Lillian McDermott, director of the Physics Education Group at the University of Washington in Seattle, one of the oldest science-education research programmes in the United States. McDermott and others say they encourage anyone interested in improving science education, but demand the same rigour in testing new methods as in any other discipline.

McCray, for instance, has drawn fire from education researchers for not using the ADT or another established tool to measure the

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success of his astronomy course. Now that the course has developed over many years, McCray says he will this year begin to test student learning, using the Student Assessment of Learning Gains tool, an online student survey to measure how well an instructor’s teaching methods have helped students learn.

Zeilik says that many instructors are not willing to use the ADT and other proven assessment tools because they fear that they will not pass inspection, or that testing will reveal gender or other bias in their courses. And Ebert-May warns that some newcomers to the field are in danger of wasting their enthusiasm on experimental teaching projects that largely repeat what has gone before. “Does someone need to test peer instruction again? No, we know it works and now we’ve moved on to more sophisticated things,” she says.

But scientists, including McCray and Wieman, complain that some current assessment tools do not properly test whether students grasp concepts in the same way that an expert would. What’s more, they say, science-education research must strive not only for learning gains, but also for methods that are practical, given the resources of research faculties. “This is a problem with much education research,” says Wieman. “They produce models for teaching as if time and cost are no object.”

This culture clash between scientists and

science-education researchers may settle into a peaceful collaboration as more scientists join the movement. Ebert-May agrees that assessments need to move beyond simple multiple-choice tests in order to be able to measure critical scientific skills. She and others say the most important goal is to raise awareness among researchers that interactive, enquiry-based instruction works better than lecturing. With enough experts giving their advice on scientific content, assessment tools will improve. Conversely, by drawing on research that shows which classroom techniques make the grade, learning will hopefully improve, too.

McCray says the two groups have begun to build bridges, and he is confident that the new teaching methods will catch on, partly because it is becoming more difficult for research universities to cling to the traditional introductory courses designed to filter out the scientists from the English majors. “We can’t stay in this state where it doesn’t matter if you learn anything,” says Klymkowsky. Instead, says McCray, teachers should start reaching the majority, not just the minority of scientifically inclined students who will succeed no matter how the class is taught: “We need to reach that middle group of students who can become scientifically literate.” ■

Kendall Powell is a science writer in Broomfield, Colorado.

Richard McCray’s Astronomy 1020 course

♦ [cosmos.colorado.edu/astronomy](http://cosmos.colorado.edu/astronomy)

Physics Education Technology project

♦ [www.colorado.edu/physics/phet](http://www.colorado.edu/physics/phet)

Project Galileo

♦ [galileo.harvard.edu](http://galileo.harvard.edu)

Biology Concept Inventories

♦ [bioliteracy.net](http://bioliteracy.net)

Astronomy Diagnostic Test & Force Concept Inventory

♦ [www.flaguide.org](http://www.flaguide.org)

Physics Education Group

♦ [www.phys.washington.edu/groups/peg](http://www.phys.washington.edu/groups/peg)

## Those who teach, learn

For many people, science literacy begins and ends in childhood — which is why some researchers who are exploring ways to improve undergraduate science education are also trying to turn their students into tomorrow’s school teachers.

Mike Marder, for instance, co-directs the UTeach programme, a collaboration between the Colleges of Natural Sciences and Education at the University of Texas at Austin. The four-year programme enrolls roughly 180 students each year, who finish with both a science degree and a teaching certificate.

“These are typical students,” says Marder. In the beginning, he says, they have a fairly shaky grasp of the subject matter. “That’s just not

acceptable for a teacher.” So Marder and his colleagues have students design their own experiments, give presentations, prepare lessons and eventually go to local schools. They also meet with ‘master teachers’ — former high-school science teachers who help them perfect their classroom technique.

Marder says the programme’s success is not just in the number of science teachers it has produced, but also in the number and type of students it draws to science more generally. The percentage of UTeach students who stay in their science major subject is double that of the university’s general science majors. The programme also attracts and retains more women

and minorities, both of which are typically underrepresented in the sciences. UTeach has 64% women and 26% Hispanics, African-Americans and Native Americans, whereas the College of Natural Sciences has just over 50% women and a minority population of 17.5%.

At the University of Washington in Seattle, students who wish to earn a certificate to teach high-school physics must take Physics by Inquiry, a course that exposes them to the same pitfalls that their future students are likely to meet. Even those who majored in physics must take the course, says Lillian McDermott, director of the university’s Physics Education Group. “They go through that relearning process to get them

closer to the way they should be teaching,” she says.

For students who are unsure if teaching is in their future, Richard McCray’s learning assistantships at the University of Colorado give top candidates a taste. The programme is one of 18 funded by a Science, Technology, Engineering, and Mathematics Teacher Preparation grant from the National Science Foundation to encourage bright science scholars to consider a teaching career.

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♦ [www.uteach.utexas.edu](http://www.uteach.utexas.edu)

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