Reintroducing the Intro Course

Physicists are out in front in measuring how well students learn the basics, as science educators incorporate hands-on activities in hopes of making the introductory course a beginning rather than a finale

Hands-on. Use of Workshop Physics means all labs and no lectures for these Dickinson College students.

Bonnie Simon, a junior at the University of Maryland, College Park, didn't relish taking a year of introductory physics. But the nutrition major needed the course to get into medical school. "I expected to memorize formulas and plug in numbers," she recalls —the same kind of unenlightening busywork that she says made high school physics a waste of time.

Instead, she found herself engrossed in—and mastering—the subject. Her teacher was using an innovative workbook, called *Tutorials in Introductory Physics,** that required her to make predictions, observe, and discuss. "It forced you to understand," Simon says, recalling how she wired light bulbs into simple circuits to figure out the relation between voltage and current. "You really got an 'Aha!' feeling."

Simon isn't the only student to feel the effects of the workbook. Created at the University of Washington, Seattle, a longtime powerhouse in physics education research, the tutorials have been extensively tested in physics departments across the country. In fact, physicists have led the way in rigorously evaluating and implementing a range of reforms to intro courses. Chemists are hot on their heels, while most biologists are still trying to decide what belongs in an intro course. This summer astronomers joined the fray, hoping to improve one of the most popular intro science courses for nonscience majors.

Figuring out what works is vitally important to the country, say U.S. educators. Each year, hundreds of thousands of U.S. students get their only exposure to science in an intro class—and most leave without understanding how science works or with any desire to take further courses. "How well we do in intro courses will ultimately decide how well we do in reforming undergraduate science," says Jeanne Narum of Project Kaleidoscope, a network of education reformers based in Washington, D.C.

Identifying the problem

Although introductory courses all present a subject for the first time, they come in many varieties—from a single course that fulfills a distribution requirement to a three-course sequence for majors. But too many instructors, say reformers, still engage in the stalest form of pedagogy: nonstop lectures to hundreds of faceless students who sit and listen passively. Supplementing the lectures are textbooks thick with facts and figures and thin on concepts and process. End-of-the-chapter homework problems and cookbook labs are solved by "plugging and chugging" numbers into equations. All of it leaves biologist Dan Udovic of the University of Oregon, Eugene, wondering: "Where did we ever get the idea that we could teach science in large lecture halls?"

The current reform movement goes back to the 1980s, when mathematicians recognized that calculus courses weren't serving the needs of many students. Physicists soon reached the same conclusion. The most recent self-examination is being done by astronomers. The sense that Astronomy 101 "is not doing what it should" led Bruce Partridge, an astronomer at Haverford College in Pennsylvania and education officer of the American Astrophysical Society, to convene two unprecedented strategy sessions this summer for 35 department heads or other leaders from large research universities. They agreed that the intro course should focus more on critical thinking skills and less on details valuable only to the few students who would end up majoring in the field. By early next year, Partridge hopes to turn these ideas into a set of guidelines for improving intro courses.

One idea that the astronomers are gravitating toward is the principle that students understand a concept better if they construct it themselves, step by step, rather than being told what it is and asked simply to remember it. This so-called active learning has become a popular strategy for reforming all manner of introductory courses, from asking students to predict the outcome of a hypothetical situation to sharing information in labs and group discussions.

Forceful measures

But do these approaches work? Data are lacking on whether active learning actually increases the number of students who choose careers in science or broadens support for science among the general population. At the same time, several studies suggest that it can improve student attitudes toward science. For example, a consortium of chemistry instructors called ChemLinks/Modular Chem found that 94% of students engaged in active learning at 13 institutions had more confidence in their ability to do science, compared with 56% of students who completed a traditional intro course. And Andrei Strau-

* *Tutorials in Introductory Physics*, Preliminary Edition, Lillian C. McDermott, Peter S. Shaffer, and the Physics Education Group, University of Washington (Prentice-Hall Inc., 1998).

CREDIT: A. PIERCE BOUNDS/DICKINSON COLLEGE

SOURCE: E. REDISH AND R. STEINBERG, *PHYSICS TODAY* (JANUARY 1999)

Information Overload Hampers Biology Reforms

The biology department of Hope College in Holland, Michigan, readily agreed to revamp its introductory course to add more principles and remove a few facts. But the consensus dissolved when the faculty began to discuss what to leave out.

"We had faculty members counting how many lectures there were on each topic," recalls molecular biologist James Gentile, then department chair. "If there was one on chloroplasts, there had to be one on mitochondria as well." Faced with a stalemate—and several hundred thousand dollars from the Howard Hughes Medical Institute (HHMI) in Chevy Chase, Maryland, to spend—a compromise was struck: Add a new course that focuses on concepts and retain the old course.

That 1997 skirmish reflects the difficulties facing biology reformers who try to improve introductory courses. In addition to the mind-boggling diversity of the field, from molecules to ecosystems, biology also lacks an encompassing professional organization that can help impose order, like the American Chemical Society with its enormous general meeting and its well-read *Journal of Chemical Education*. In addition, soaring enrollments shield biologists from the pressure felt by their colleagues in the physical sciences, who see reform as the key to reversing a downward trend in student interest.

The movement isn't lacking for money. Over the last 13 years, HHMI has dropped $154 million into 225 biology departments to improve the curriculum and upgrade labs. Those grants, an amount that dwarfs efforts by any other major player, have allowed educators to create or significantly improve more than 3200 biology courses. And HHMI has deliberately avoided being too prescriptive. "I don't know that there's a single model that would work for everyone, or even for most [departments]," says HHMI program officer Steve Barkanic, who encourages programs to describe their vision and what they need to achieve it.

Although HHMI's munificence has built what biologist John Jungck of Beloit College in Wisconsin calls a "fabulous infrastructure" for undergraduate research, he says the grants haven't promoted systemic change nor generated the "intensity of discussion" that followed the National Science Foundation's initiatives in chemistry and mathematics. HHMI "hasn't had as much impact on the pedagogy as I would like to see," Jungck adds, noting that large lectures are still a hallmark of introductory biology courses at most major research universities.

Reformers aren't giving up, however. This month the National Research Council sponsored a 3-day meeting in Colorado to explore the undergraduate biology curriculum, including the role of mathematics, physics, and chemistry in introductory courses. Its forthcoming report, due out next summer, will be a "major catalyst for conversation," predicts Gentile, who helped organize the meeting. —E.S.

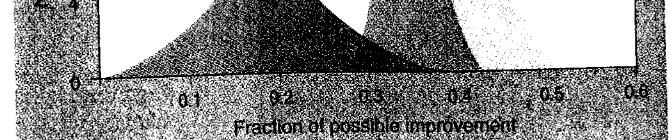
manis, now a postdoc at Sandia National Laboratories, says that active learning reduced dropout rates by 38 percentage points in a large organic chemistry class at the University of New Mexico in Albuquerque.

The most common way to gauge the success or failure of efforts to reform the intro course is to see how thoroughly students digest the material being taught. But traditional measures can be misleading if they don't require students to understand the material. In a traditional intro chemistry course, for example, Mary Nakhleh of Purdue University in Lafayette, Indiana, found that about half of the students who solved test problems couldn't explain the underlying concepts. Traditional tests may hide that fact, warns John Moore of the University of Wisconsin, Madison.

So Moore, Nakhleh, and a handful of other researchers have tried to come up with more accurate tools, based on extensive interviews with students. "These tests are not trivial to design," says physicist Edward "Joe" Redish of the University of Maryland, College Park. One of the most widely used is the Force Concept Inventory (FCI), the first version of which was published in 1985 by physicist David Hestenes of the University of Arizona in Tucson. The FCI is a battery of 29 multiple-choice questions that explore Newtonian mechanics. Although some researchers have questioned whether high scores actually demonstrate improved understanding, the test shook up the physics community when it revealed that even top students retain misconceptions about important concepts. "The FCI got people to pay attention to the fact that their students weren't learning [the key concepts] in intro courses," says David Sokoloff, a physicist at the University of Oregon, Eugene. For example, a basic point in introductory physics is that every force has an equal and opposite force. But the FCI shows that most students, even after hearing a lecture on that topic, still think that a hefty Ford Navigator will exert a greater force on a Toyota Corolla during a collision. (The much lighter Corolla, however, will experience greater acceleration—and more damage—because it has less mass.)

The FCI has also shown that active learning improves student understanding (see figure). A 1998 analysis of 6542 students in 62 introductory courses at several universities, community colleges, and high schools found that students upped their scores on the FCI by an average of 48 percentage points after completing courses that emphasized active learning. Students in traditional courses improved by only half as much, reported Richard Hake of Indiana University, Bloomington, in the *American Journal of Physics*. A 1999 study by Jeff Saul (now at the University of Central Florida in Orlando), Richard Steinberg (now at the City College of New York), and Redish found that students at 14 schools who have completed a traditional intro course answer about half of the questions correctly on the FCI. Student scores rise to 60% when instructors "teach to the test" in these courses, spending extra time explaining the Newtonian concepts covered on the inventory. They reach 70% when the traditional problem-solving recitations are replaced with *Tutorials in Introductory Physics*.

Students perform even better in an intensive class that emphasizes active, inquiry-based learning. Workshop Physics, a course designed by Priscilla Laws and colleagues at Dickinson College in Carlisle, Pennsylvania, features 6 hours a week of hands-on labs and no lectures. All three of the department's lab rooms were designed so that students face each other in small groups (see picture). Students who have taken this kind of course typically answer up to 85% of the questions correctly on the FCI.



More is better. The greater amount of active learning in Workshop Physics seems to increase understanding, too.

SOURCE: E. REDISH AND R. STEINBERG, *PHYSICS TODAY* (JANUARY 1999)

CREDIT: A. PIERCE BOUNDS/DICKINSON COLLEGE

Building up the ranks

The use of the FCI and other assessment tools has helped physics educators be leaders in evaluating undergraduate curriculum reform. "Nothing in the biological sciences can compare to it," says Oregon's Udovic, who developed a test to evaluate changes he and colleagues made to their large introductory biology course. "We have a ways to go to come up with a conceptual instrument that everyone agrees on and that could be used in a standardized way."

Physics reformers emphasize that coming up with multiple-choice assessment tests like the FCI requires a basic research program that must focus first and foremost on identifying student difficulties with a subject. One reason for physics' head start is an increasing flow of scientists into the field. A pioneering program in physics education research begun in the 1970s by Lillian McDermott at the University of Washington has spawned similar research groups in physics departments across the country, including the Maryland group begun in 1993. "We have decided education research is too important to leave to anyone else," says Redish.

Graduate students in these groups take the same advanced courses as other doctoral students, but their research investigates how students learn physics. They get jobs, too: The number of tenure-track jobs in physics education research has risen from just five in 1996 to 35 last year. "It's great to have someone in our building who knows the findings about the best ways to teach physics to college students," says condensed matter theorist Susan McKay, chair of the physics department at the University of Maine, Orono, which recently hired physics education researcher Michael Wittmann. Physicists also have an inherent advantage in assessing student understanding: Physics 101 is based much more on first principles than, say, introductory geology. "Most of physics is about reasoning," Laws says. "It's closer to the fundamentals of science." It's more difficult to assess understanding in fields that are heavy on content rather than fundamental relationships. "Biology and chemistry instructors," Laws says, "have a much more daunting task."

That isn't holding them back, though. Assessments of biology and chemistry students have found that active learning techniques enrich introductory courses in those fields, too. Not every study has found a statistically significant difference, but the few meta-analyses suggest overall improvements in learning. And most reformers say that qualitative assessments such as interviews and analysis of student writing back up that conclusion. "The whole picture reveals a vast improvement over what was happening before," says biologist Marshall Sundberg of Emporia State University in Kansas.

Biologists have the advantage of their own sugar daddy. Since 1988, the Howard Hughes Medical Institute in Chevy Chase, Maryland, has given away $154 million for undergraduate curriculum development and laboratory improvements, largely for introductory courses. But the results haven't produced any breakthroughs (see sidebar on p. 1609).

In chemistry, the National Science Foundation (NSF) in 1995 gave out $10 million to five consortia of universities and colleges to support various approaches, including student-led workshops, weeks-long modules that focused on teaching chemistry through hot-button societal and environmental issues, and Web learning (see sidebar above). "We're all still struggling with" what works best," says Chris Bauer, a chemist at the University of New Hampshire, Durham. "The significant thing is that now there's a huge network of chemists who have become involved in these reform projects," says NSF's Susan Hixson.

What those chemists and other reformers ultimately want are intro courses that do more than simply serve as gatekeepers for science majors. They would like to get all students to think scientifically. It worked for Simon, now a senior who plans to apply to medical schools next fall. One day she found herself thinking about Newtonian mechanics while gazing out at traffic. "I feel that I really know physics well," she says. "It helps you with figuring out things in life."

–ERIK STOKSTAD

One on one. Physics educators such as the University of Maryland's Joe Redish (at right) often evaluate videotaped interviews to figure out what lessons stump students.

CREDIT: MARTY KATZ

Reading, Writing, and Chemistry Are Potent Mix

Orville Chapman of the University of California, Los Angeles (UCLA), thought that getting his introductory chemistry class to write about the subject would help students understand the material better. But he didn't want to read and grade hundreds of essays each week. Borrowing a page from scientific peer review, Chapman and UCLA colleagues decided to have students grade each other's papers using a computer program, called Calibrated Peer Review (CPR). Four years later, more than 16,000 students in chemistry, biology, economics, and other departments at more than 100 institutions have used the writing technique to learn more about their subjects.

The process begins with an essay assignment. Students submit a brief essay on the question—say, the role of nitrogen compounds in ozone destruction—and file it on a Web site (cpr.molsci.ucla.edu). The program then asks the student to read and grade three essays of varying quality that were written by an instructor; it's a test to measure their ability to judge style and content. Those who need more training are given more sample essays.

Once they've passed that step, the students evaluate three papers written by peers. Finally, they grade their own essay. Each student gets a report summarizing the comments of other students.

Preliminary evaluations show that students in chemistry and biology classes score on average 10% higher on midterm and final exam questions related to topics studied using CPR than on topics taught by traditional methods. "That's a profound gain in learning," says Arlene Russell, a chemist and education researcher at UCLA. "When you review someone else's work critically, you start thinking about [the topic] differently."

The program gets high marks from other faculty members. "It's just extremely well conceived, very carefully put together," says Steve Watton, a chemist at Virginia Commonwealth University in Richmond, who used the program with graduate students to test its value within smaller groups of more advanced students. "My hope was to get them to think a little harder about what we try to teach them." Next spring Watton plans to incorporate the technique into his introductory course.

–E.S.