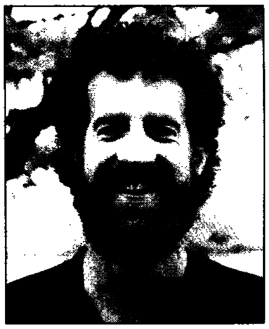
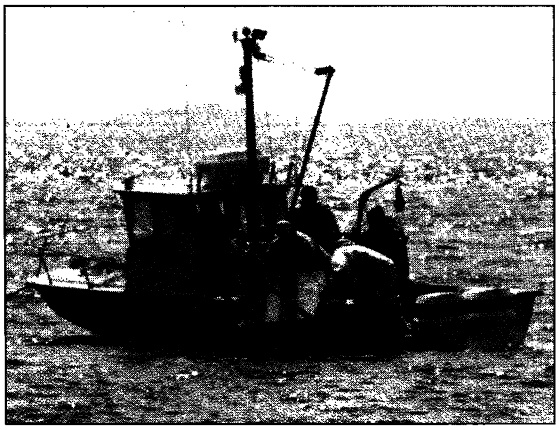
five marine engineering students. (Who else would name a research project after a beer?) The group chose the idea from among several proposed on the first day of class by UNH marine biology professors and was given \$3000 to carry out its plan. The professor was available for advice, and the entire class met monthly so teams could share their progress.

The "test" came 9 months later, when each of the four teams in the class presented its work to students, faculty, and marine-industry researchers and consultants. The AMSTEL group had designed, built, and operated a high-tech lobster trap, complete with underwater lights, video camera, and computer, that provided evidence of the low success rate of the typical lobster trap. Like many projects in the course, AMSTEL grew into an extended effort involving professors and graduate students.



For students contemplating life as a university researcher, the issues of budgets, engineering constraints, and teamwork raised in the course are invaluable, says Stephen Meriney, an ocean engineering alumnus who is now a neuroscience researcher at the University of Pittsburgh. "It exposed me to some of the realities of research that most undergraduates never see," he says about a project to build a tank to study the extent to which sea snails are attracted to light. "It was an introduction to a career."



PHOTOS BY STEVE ADAMS

Win-win situation. Win Watson helps New Hampshire students deploy their high-tech lobster trap.

The course also benefits those students—probably a majority—who don't end up as professors, believes UNH marine biologist Larry Harris. "Most of these biology students won't get Ph.D.s," he says. "But they might end up working for environmental consulting firms or government agencies where they'll have to interface with engineers and deal with all sorts of technical problems."

Indeed, Vetrovs credits the ocean engineering course with giving him the necessary business as well as technical skills to start his own business. "Unless you're only interested in doing straight observation, it really helps biology students to get as much broad-based experience as possible," he says. Any biology major thinking of sending Vetrovs a resume should probably take note.

–David Freedman

Why Eric Mazur Brings Chaos—Not Chaos Theory—to Physics

Arguments are common during Eric Mazur's undergraduate physics course. These outbursts from students don't upset Mazur, and it's not because he ignores them. Instead, the Harvard University physicist calls them "wonderful chaos"—and says they are one goal of a teaching style that combines peer instruction with concept-based learning.

This approach has made Mazur a rising star on the science education circuit. One of only two physicists invited this year to a special Gordon Research Conference on chemistry education, he receives at least as many invitations to speak on his lecturing as on his research into optics. The National Science Foundation is giving him money to develop additional materials and quantify his classroom results; he's mailed out more than 200 copies of his teaching guide; and he has received glowing attention in *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't*, a book by education researcher Sheila Tobias.

But Mazur hasn't always been in such demand for his classroom activities. Only a few years ago, he discovered that his students in introductory physics—a required course for science and engineering majors—were not learning as much as he thought. Although they scored well on complicated problem-solving exams and gave him glowing evaluations, they didn't do nearly so well on a quiz developed by David Hestenes of Arizona State University that tests basic understanding of Newton's laws of mechanics.

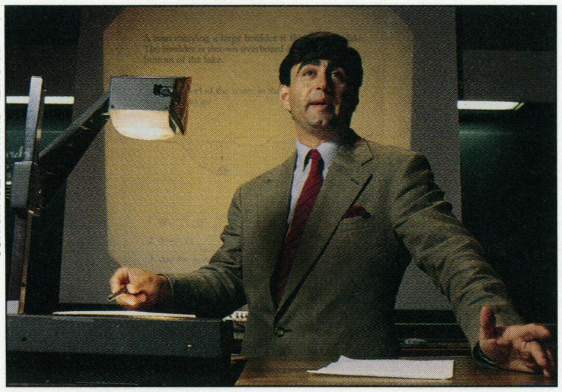
Hestenes' quiz had been making a stir in the education community after his data showed students could not correctly answer seemingly simple questions. To test their grasp of Newton's third law—that for every action there is an equal and opposite reaction—Hestenes asks them to compare forces in a collision between a heavy truck and light car. Even after a year of physics, most still thought, incorrectly, that the truck exerted more force on the car. Mazur's students scored no better than their peers when they took Hestenes' exam. "The results were devastating," he recalls. "It was nowhere near what I wanted."

After searching his soul and talking with his students, Mazur reached a disturbing conclusion: "We put too much emphasis on the equations and not enough on understanding," he says. Instead of mastering a concept, he says, the students had learned to apply problem-solving strategies and were "plugging and chugging" their way through equations.

Mazur wanted to find a way to challenge his students to think without making radical changes in the traditional, large-lecture format. The result: In addition to more concept-based questions on his exams, Mazur flashes what he calls "Conceptests" on an overhead computer display three or four times during his 2-hour lecture. The star Antares and the neon signs in Harvard Square both shine red. Are they at the same temperature? Or a spinning roulette ball suddenly encounters a large gap in the wheel. What happens?

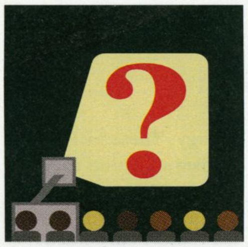
Each student has a minute to puzzle though such questions, which demand no mathematical equations or complicated problem-solving skills. Then Mazur asks his students to talk with their classmates and to resolve any disagreements. "Some of the discussions are truly marvelous. They sound like faculty members talking to one another," says physicist Albert Altman, who is using Mazur's ideas at the University of Massachusetts in Lowell. Besides helping his students, Altman wants to refute critics who say this approach only works at elite schools.

In the absence of any outside evaluation, the early returns on Mazur's methods are positive. Students have gotten better at answering Hestenes-like questions and seem much more involved in the course, says Mazur. Altman jokes that it's difficult to sleep through one of his classes because of the Conceptests. And



JON CHASE/HARVARD NEWS SERVICE

Quizmaster. Eric Mazur interrupts his physics lectures to give frequent "Conceptests" on an overhead computer.



there are other benefits as well. The quizzes provide quick feedback to lecturers and build self-confidence among students who grasp the concepts and explain them to others. "Just being able to explain really helps them learn it better," says Patricia Allen of Appalachian State University, who is also examining gender differences within this peer-instruction approach.

And from observing his students in action, Mazur has learned that undergrads can outshine their professors in the classroom. "A student who understands [a concept] is sometimes better at explaining it to others than I am," he says.

–John Travis

Turning Students On by Simulating the Arcane

Carnegie Mellon University physicist Bruce Sherwood could never figure out how to teach Ampere's law, which explains the relationship between magnetic fields and electric currents. "You could lecture until you were blue in the face, but the students just didn't get it," Sherwood said about his introductory course in electricity and magnetism for science majors. So Sherwood turned to something his students were sure to understand.

The computer. With the help of an overhead screen that makes his monitor visible to students, Sherwood uses a mouse to explore the simulated magnetic and electric fields generated by a current-carrying wire—and how those fields are altered by other distant charges. The result, called EM Field, gives students an intuitive feel for how the formal, calculus-based laws of physics work in the real world. It has also raised test scores. "With this tool, we've just cut through a big problem students always have visualizing electric and magnetic fields," says Sherwood, whose EM Field was a winner in the 1991 Computers in Physics educational software contest.

In classrooms and labs in universities across the country, more and more students are pointing and clicking their way through explorations illustrating the abstract laws of physics or the three-dimensional structure of proteins. They are also tutoring themselves in chemistry and calculus. These new computer tools are even replacing some of the time students spend in traditional wet labs. "It has totally transformed the way we teach introductory chemistry," says University of Illinois, Urbana-Champaign, chemist Stanley G. Smith.

Students starting Chemistry 101 at Illinois walk into a "lab" with 80 personal computers and workstations and log on to the campus network. Within seconds, they're given a choice of lessons—including videodiscs of laboratory experiments that they can control. One experiment, for example, allows them to explore different chemical reactions—and shows them the results. Students can tell the computer to add aluminum to a beaker of bromine and watch the solution flare up into a fiery reaction on their screen. "We film it from the student's point of view," says Smith. "It's what you'd see if you were doing it yourself in the lab."

The computer has cut in half the amount of time students spend in the wet lab. "This replaces lab experiments that are too expensive, too hazardous, too complex, too time-consuming," says Smith. It also gives students a chance to set their own schedules. "I think it's great, because I could work very slowly until I understood it," says Jenny Schwab, a sophomore at Illinois. "It's not the most exciting way to spend a weekend, but I could work at my own pace." Adds Smith, "You can now do your chemistry from the library."

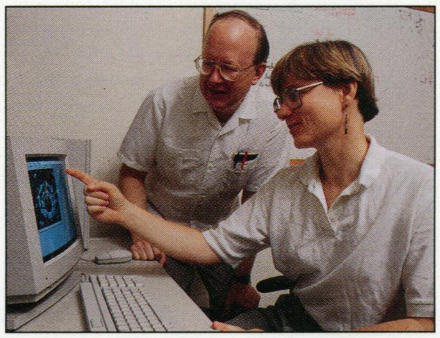
Computers can also save students time. A new "Tech Commander" computer system at Vanderbilt University in Nashville, Tennessee, is helping 260 premed and biology students reduce the number of errors they make in a molecular biology lab course. They preview experiments on their computer, looking at video images of their electrophoresis gels or microscope specimens, says Vanderbilt systems analyst Steve Garrison. "It doesn't replace the lab, but it makes them more efficient."

The best computer software speeds up the learning process by showing students real-world applications of the abstract concepts they learn about in lectures and textbooks. Many physics students, for example, can solve the calculus-based equations at the heart of many laws of nature, but they lack an intuitive feel for how they work. "We want to construct an environment where they can do much of what real scientists do—apply a few fundamental principles to a broad range of phenomena," says Sherwood, who has written several prize-winning physics software programs with his colleagues at Carnegie Mellon's Center for Design of Educational Computing.

But as much fun as these new tools are to use, they're no substitute for a faculty member's presence in the laboratory or the lecture room. "If you are trying to mimic human teachers, you're going to fail," says Sherwood. "A computer doesn't see a student's facial expressions. It doesn't see who's looking out the window, or that this student is interested in ceramics." Not yet, anyway.

–Ann Gibbons

Seeing is believing. Students play Ruth Chabay's "Electric Field Hockey" *(bottom)* to learn how force fields vary with distance; Chabay and Bruce Sherwood *(top)* look at "EM Field."



PHOTOS BY KEN ANDREYO