Stephen Thompson: Call Him Czar of Small-Scale Chemistry

Bulky beakers, rusty ring clamps, test tubes, and Bunsen burners aren't part of Stephen Thompson's lab. Instead, his chemistry students use "tubular integrated containers," "environmental chambers," and "sci-plexes." But don't think these tools are the latest in high-tech equipment. Tubular integrated containers, which serve as everything from clamps to filtration columns to ring stands, are really soda straws, and the environmental chambers in which chemical reactions occur are Petri dishes. Magnifying glasses are microscopes. Styrofoam cups are integral parts of a gas thermometer, and trays with microtiter wells, the mainstay of molecular biologists, hold chemicals for spectroscopic analysis.

Crude tools, yes, but each year 2800 students at Colorado State University in Fort Collins use them to analyze vitamin C concentrations, develop a chemical test for intoxication, perform redox reactions, and study acid-base equilibria. For Thompson, who directs the undergraduate chemistry laboratories at Colorado State, the methods in his madness began a few decades ago and are spelled out in his textbook, *Chemtrek*. And they serve several purposes.

Small-scale chemistry is cheaper, for one: Indeed, Colorado State's costs for "consumables" in student labs has dropped, Thompson says, from more than $50,000 a year to less than $5000. "Molecules are extremely small, and 50 billion of them do the same as 5000 billion," he says. Then there's the waste disposal advantage: Small amounts of chemicals mean there's less to be rid of. And best of all, according to Thompson, students forced to work with small-scale equipment draw large-scale lessons they won't forget.

Thompson is convinced the small-is-beautiful approach moves students away from following recipes and toward thinking about how chemists know what they know. It "allows people to play," he says, which, in turn, allows people to learn. Moreover, in Thompson's small world, students must build most of the instrumentation they use. "I want students to see the relationship between form and function," Thompson says. "There's a tremendous difference between the tools and instruments needed for research and the tools and instruments needed for *teaching* research."

For example, Thompson's students analyze a chemical not with a $15,000 gas chromatograph but with a 25-cent contraption that they build themselves using such low-tech gear as clothes pins and syringes. "Steve is trying to take the black-box mentality out of science and show that it's what's inside the black box that matters," says Frederick Stein, a physical chemist who directs Colorado State's Center for Science, Mathematics, and Technology Education. The center carries the small-scale gospel to middle school and high school teachers throughout Colorado.

In fact, Stein believes so strongly in the concept that he has helped raise money for Thompson to purchase "sci-plexes" for his undergraduates. These are computer workstations, shaped like boomerangs, where small-scale experiments are carried out on screen. The two advantages: Students can load their lab notebooks on the machines and directly enter data, and the light from the screens can be used in experiments to, say, illuminate the scattering of gas molecules that are in a Petri dish.

PHOTOS BY WILLIAM A. COTTON

Edutainer. This Colorado State chem lab director passes up high-tech for magnifying glasses, styrofoam cups, and soda straws.

An impish man with bushy white eyebrows and a lilting British accent, Stephen Thompson is a born entertainer: He put himself through graduate school by working as a fire eater in the circus. Ever since, Thompson has been breathing fire into the sometimes all-too-tepid traditions of undergraduate chemistry.

–Jon Cohen

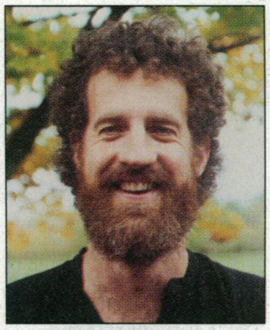
Ocean Engineering? New Wave In Teaching Marine Biology

Alex Vetrovs came to the University of New Hampshire (UNH) to obtain a Ph.D. in biology and to become an academic scientist. But an unusual undergraduate course in ocean engineering gave him a taste for the real-world intersection of science and commerce, and in 1985 he left school after completing a master's degree to start Aquatic Research Instruments, a small Seattle company that makes electronic equipment for marine researchers. "Biology students are usually interested in learning things," says Win Watson, a UNH biologist who often oversees the course, begun in 1969. "But this teaches them how to solve a problem in the real world."

Vetrovs was part of a team of a half-dozen undergraduates in marine biology and engineering who designed, built, and operated a system to monitor the behavior of ocean-dwelling horseshoe crabs. The system detected electrical impulses in the crabs' muscles and relayed the signals to a recorder in a floating buoy. It was a rare opportunity: Few classes give students the chance to go beyond turning knobs on a research project, and even schools offering research opportunities for undergraduates seldom give students as much independent and hands-on experience as does the ocean engineering course, which is supported by the National Oceanic and Atmospheric Administration's Sea Grant program. "That project showed me the possibilities," says Vetrovs. "It's how I first learned to work with engineers to get a product out."

Unlike the typical undergraduate marine biology course, ocean engineering judges students not just on what they know but also on how well their ideas work. Take the Automatic Monitoring Systems to Evaluate Lobsters (AMSTEL), a project designed to test the theory that lobster traps snare only a tiny percentage of the crustaceans they attract. AMSTEL was created by an undergraduate team of a marine biology major and 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