Peaceful Revolution

Agents of change plot reforms in undergraduate biology education.

Looking a little like revolutionaries—which in some sense they are—a band of university professors huddles around a computer terminal in a dark corner of the university conference center. The clock edges past midnight as they wrangle about tactics.

Their mission? Nothing less than revolutionizing the way biology is taught to undergraduates.

"Most introductory courses rely on lectures and 'cookbook' labs, even though research shows that those techniques are not highly effective in fostering conceptual understanding or scientific reasoning," says Jo Handelsman, professor of plant pathology at the University of Wisconsin–Madison and one of 20 HHMI Professors who received $1 million each to support reform of undergraduate science at research universities. Handelsman believes the reason for this lack of innovation is that "scientists actively resist changing their teaching." To move them, she asserts, is going to take nothing less than a revolution.

To help plant the seeds of that uprising, Handelsman, who directs HHMI 's New Generation Program for Scientific Teaching at the University of Wisconsin–Madison, teamed up with William B. Wood—a professor of molecular, cellular, and developmental biology at the University of Colorado at Boulder—and others on a planning committee commissioned by the National Academies. They invited leading life-sciences faculty to come with a junior-level colleague to spend a week during August 2004 at the University of Wisconsin, working in teams and in plenary sessions to inform, plot, and inspire the insurrection.

More than 100 applied for the Summer Institute on Undergraduate Education in Biology, which grew from a recommendation in the National Research Council report *Bio2010: Transforming Undergraduate Education for Future Research Biologists.* (Both the summer institute and the report were projects of the National Academies and funded in part by HHMI.) Ultimately, 42 faculty members from 20 research universities met in Madison to learn from some of the pioneers in undergraduate biology education and to create their own "teachable units"—a cohesive collection of materials and activities on a topic in biology, designed to be the equivalent of three lectures—for conveying scientific thinking and biological concepts at the introductory college level.

Jo Handelsman wants to transform science teaching.

"Can students learn to think in Bio 101?" speaker Randall W. Phillis, an associate professor of biology at the University of Massachusetts–Amherst, asked rhetorically. Phillis, who won a grant from the Pew Charitable Trusts' Center for Academic Transformation to revamp the introductory biology courses on his campus, said the answer is an emphatic yes. Through "active learning," which he defined as problem-solving using questions and activities, students become "active participants in learning instead of passive recipients of knowledge," said Phillis.

Active learning does not replace the content of the course itself. "Content is important," he noted, "but it is learned best if it is used in the context of doing science."

Another speaker, Robin Wright, an administrator and professor of genetics, cell biology, and development at the University of Minnesota, called active learning "hands-on, minds-on, dynamic, engaging, and uncomfortable." She added: "We are not teaching students biology; we are teaching them how to be human beings—to think, to be curious, to make difficult decisions, to apply what they've learned."

Whether they consciously realize it or not, students desire just these kinds of outcomes. When they ask "Do I have to memorize this for the exam?" said Lydia Daniels, director of undergraduate programs in the department of biological sciences at the University of Pittsburgh, "what they really want to know is 'How am I going to use this? Why do I need to know it?'" For example, Daniels suggests, instead of teaching math as a stand-alone subject, integrate it into biology such as by teaching equations and mathematical techniques that students need to solve biological problems, an approach consistent with the recommendations for interdisciplinary education in *Bio2010.*

Presentations by the institute's speakers, a battle-tested and inspiring lot, were but one part of the intense week in Wisconsin last summer. Participants worked virtually around the clock, attending roundtable discussions at 7 a.m. and rolling up their sleeves at midnight meetings to fine-tune their teams' teachable units. And on Friday it was show-and-tell time, when each team presented its product and received feedback from other participants and reviewers.

One team had tackled the question "Are you my mother?"—in response to its assignment to develop a teachable unit on heredity. Challenging students to solve a case of two newborns who may have been switched at birth, team members Victoria Finnerty and Rachelle Spell of Emory University, Martin L. Tracey and Ophelia I. Weeks of Florida International University, Jennifer K. Knight and William B. Wood of the University of Colorado

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at Boulder, and William Segraves and David G. Wells of Yale University would teach how to measure the degree of genetic variability between individuals and how a genetic marker segregates. In the process, the students learn the principles of genetic linkage, DNA sequence analysis, and the importance of incorporating appropriate experimental controls. They also learn a larger lesson: the use of scientific data to answer real-world questions.

Another team took on evolution. Almost all introductory-biology students have misconceptions about evolution and the relationship of genotypes to phenotypes, Phillip G. Sokolove and Jeff W. Leips of the University of Maryland, Baltimore County, pointed out. And many do not have the quantitative skills to evaluate hypotheses related to evolution. In a unit called "Are Humans Evolving? How Would You Know?" they and fellow team members Elizabeth Torres of California State University, Los Angeles; William F. Collins and Joan M. Miyazaki of Stony Brook University; and Mark D. Decker, Sue Wick, and Robin Wright of the University of Minnesota would use a case study of a genetically based human disease to teach students the Hardy–Weinberg equilibrium—an equation for predicting allele and genotype frequency in a population. After the class analyzes real data from rock pocket mice to verify the formula's predictions, it examines fossil evidence and current disease data on humans to answer the unit's title questions.

"Content is...learned best if it is used in the context of doing science." —RANDALL PHILLIS

The development of these and the other teachable units is not meant to be a mere exercise; each participant pledged to implement at least one of the units on his or her campus this academic year. Each participant also accepted the honor and responsibility of being named an Education Fellow in the Life Sciences by the National Academies.

For added motivation, Handelsman sent them off with a battle cry: "You're going home to begin staging a revolution. Find sympathetic colleagues on campus and nationally. Share your ideas. Combat misconceptions. Remember, we are doing this based on scientific evidence."

"We are the change agents," says Sokolove. But he harbors no illusions about its pace. "Will teaching ever be rewarded in a research university the way research is? Probably not. But a paradigm shift in science takes 35 years. Why should we expect a change in teaching to happen overnight?"

Nevertheless, progress is now discernible. At his own campus, Sokolove says, his colleagues are starting to talk to each other about teaching. "They never used to do that."

—JENNIFER BOETH DONOVAN

Workshop participants shared ideas on interdisciplinary teaching, undergraduate research, and curricula.