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ABSTRACT

Sharply rising enrollments in undergraduate biology, spurred by the growing importance of the life sciences in society, have led university faculty members across the country to experiment with new ways of teaching students. This report documents change in the nation's classrooms; specifically, it focuses on a sample of institutions that are incorporating innovative projects in biology education supported by the Howard Hughes Medical Institute. Chapter 1, "A World of Opportunity," details how rising enrollments and the rapid growth of biological information are contributing to profound changes in undergraduate biology education. Chapter 2, "Changes in the Classroom," describes innovative teaching methods that are bringing the life sciences to life. Chapter 3, "The Laboratory Experience," provides information about students' experiences in the biology laboratory. Chapter 4, "Faculty in the Crossfire," details the frantic yet richly rewarding lives of university faculty members. Chapter 5, "Expanding the Talent Pool," describes efforts by campuses to attract and retain women and minority candidates in biology. Chapter 6, "The Many Paths to Success," lists even more examples of new approaches to teaching and learning in undergraduate biology education. (WRM)

BEYOND BIO 101

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Creating a Community of Scholars

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EXPANDING THE TALENT POOL

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Biology for Non-Majors

with new ways of

http://www.hhmi.org/BeyondBio101

teaching students.

The result: changes in undergraduate biology education as dramatic as those reshaping

THE LABORATORY EXPERIENCE

biology itself.

A REPORT FROM THE HOWARD HUGHES MEDICAL INSTITUTE

FOREWORD

Scientists speak often of the "revolution in molecular biology" to describe the current ferment and pace of change in our understanding of living organisms. Over the past two decades a cascade of discoveries about the genetic origins of diseases, molecular functioning of the brain, and other questions has begun changing the face of the biological sciences and medicine. The breadth and impact of this intellectual revolution continue to grow.

Less noticed is the remarkable change taking place in undergraduate biology education. At colleges and universities across the United States, a generation of students is flocking to learn about the exciting developments in biology and related disciplines. They are getting involved in original research in addition to learning from lectures, textbooks, and the scientific literature. They are using powerful computers and state-of-the-art laboratory equipment, and putting their new knowledge and skills to work in scientific settings and across society.

This change in the classroom is as compelling in its way as the science itself. *Beyond Bio 101* examines how the trend is unfolding at research universities, liberal arts colleges, historically black institutions, and other campuses across the country. It focuses on institutions supported by the Howard Hughes Medical Institute (HHMI) to tell a story that involves the broader, nationwide community. It is a story whose outcome affects not only scientists and educators, but also a larger society that is facing difficult choices about health care, the environment, the economy, and many other issues involving biology.

HHMI, the nation's largest private philanthropy, is a nonprofit medical research organization dedicated to basic biomedical research and education. Its major mission, involving about 80 percent of its expenditures, is medical research carried out by HHMI investigators located in laboratories at more than 60 leading academic medical centers, universities, and hospitals throughout the United States. However, in addition to supporting cutting-edge research today, HHMI is committed to training the outstanding researchers of tomorrow. To that end, the Institute has awarded nearly $600 million through its grants program since 1988. Among its goals is the enhancement of the quality of science education for American students of all ages.

The largest of the Institute's grants programs is directed toward biological sciences education at the college undergraduate level. More than 200 public and private colleges and universities have received several hundred million dollars in grants to expand research opportunities for students, update courses and facilities, attract talented women and underrepresented minorities to science, and reach out to science teachers and schools in their communities.

This publication profiles only a sample of the programs supported by HHMI, which are themselves representative of the many colleges and universities that have begun to change how millions of young people learn about a science that is transforming their world. The goals, content, and practitioners of undergraduate biology education are all changing. *Beyond Bio 101* describes what is happening—and why it matters to all of us.

Purnell W. Choppin, M.D.
President
Howard Hughes Medical Institute

More-
house
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BEYOND BIO 101

THE TRANSFORMATION OF UNDERGRADUATE BIOLOGY EDUCATION

A REPORT FROM THE HOWARD HUGHES MEDICAL INSTITUTE

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SURFING BEYOND BIO 101

A colorful electronic version of this publication is available on the Institute's World Wide Web site. It includes links to many of the programs described in this book, and to a variety of useful resources for biology educators and students. Address: *http://www.hhmi.org/BeyondBio101*

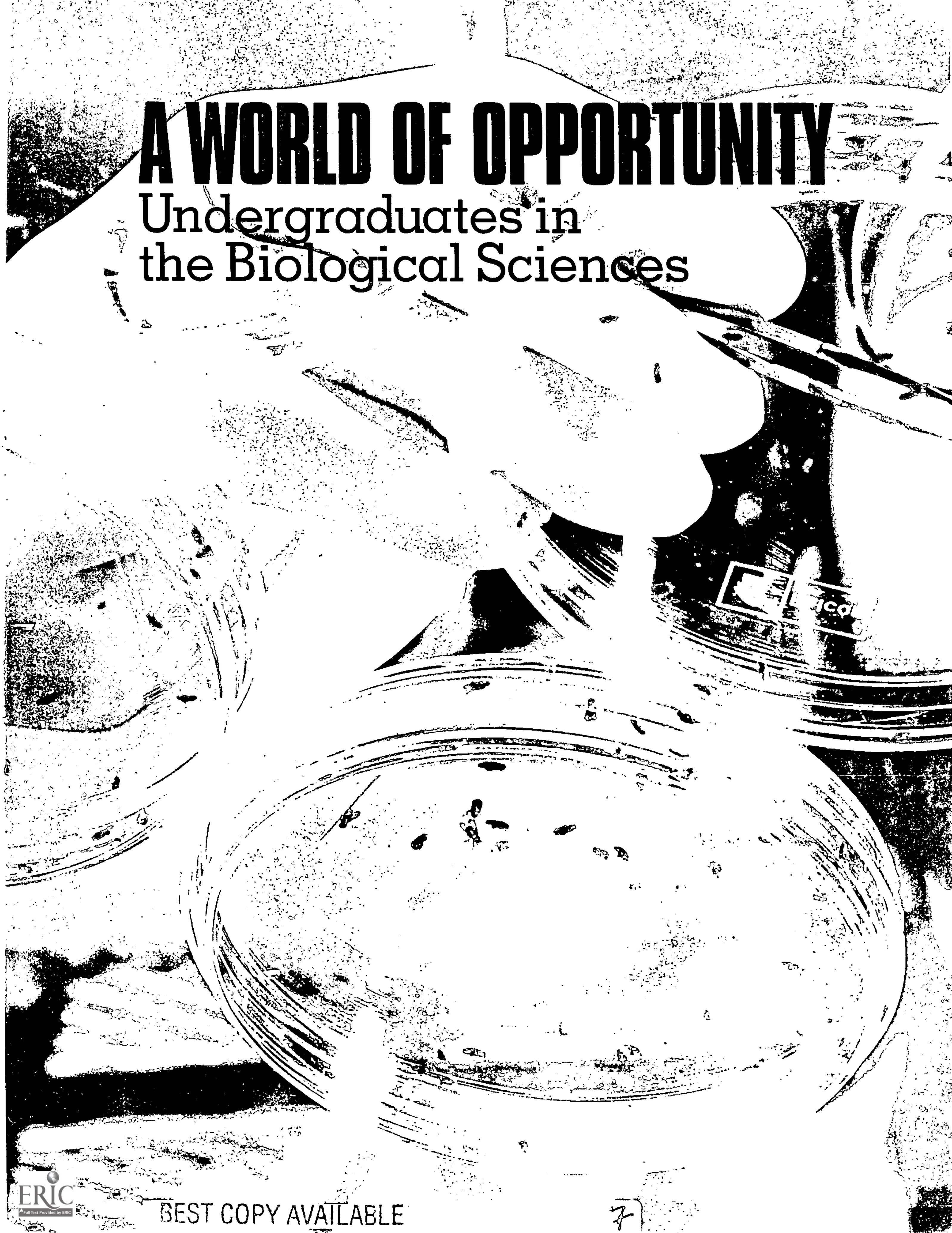
All of the institutions profiled in this report have received support from the Howard Hughes Medical Institute through its Undergraduate Biological Sciences Education Program.

The names of the colleges and universities are as they appear in the *1995 Higher Education Directory*.

Cover photographs: City College of New York (upper); Carnegie Mellon University (middle); University of Wisconsin–Madison (lower)

Inside front cover: The bright yellow hybridization signal reveals the location of the messenger for a brain protein that binds zinc. This protein helps protect against epileptic seizures.

A WORLD OF OPPORTUNITY
Undergraduates in the Biological Sciences




Gustavo Arrizabalaga went from Haverford College to graduate study in genetics.

Growing up, Gustavo Arrizabalaga always knew that he wanted to study science. What he did not know was how difficult that would be for him.

Born and raised in Puerto Rico, Arrizabalaga enrolled with a scholarship at Haverford College outside Philadelphia—and almost immediately was overwhelmed. The courses were much tougher than anything he had taken in high school. He was far away from his family and home, and he struggled to speak English fluently enough to be

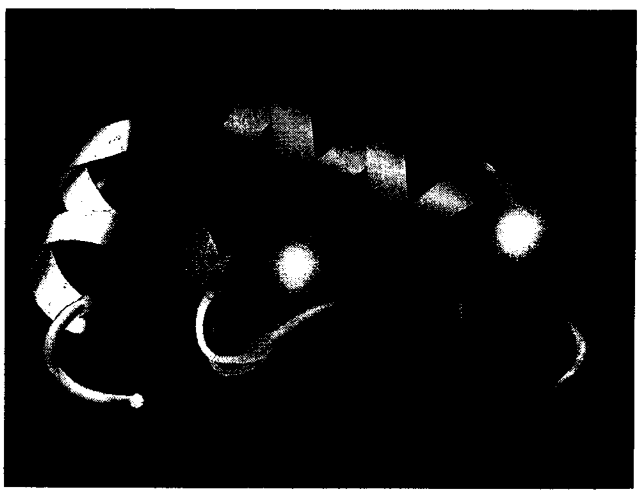

Colorful stripes distinguish developing body parts in *Drosophila* embryo.

understood. Several of his instructors wondered if he was going to make it.

Slowly he began to catch up. His English professors took him aside and worked through his papers with him. He began doing research on photosynthesis in the laboratory of associate professor Julio de Paula. "The summer of his sophomore year, when Gustavo began in the lab, he really started to blossom," recalls de Paula. "His grades got better. He started working on projects on his own, and that made a big difference."

Many of the most pressing issues in the 21st century are likely to have biological roots.

Then, in his junior year, Arrizabalaga attended a seminar by a Peruvian-born expert on the structure and function of DNA. "That was a turning point for me," he says. "I told myself that if he could do it, I could do it." Now investigating *Drosophila* genetics at the Whitehead Institute in Cambridge, Massachusetts, Arrizabalaga is about a year away from earning his Ph.D. in biology.



A computer-generated model shows the structure of the DNA-binding segment of the receptor for vitamin A.

The year he graduated from Haverford, Arrizabalaga was one of about 40,000 biology majors nationwide—a number that has since risen to more than 50,000, according to U.S. Department of Education statistics. It is a remarkably diverse group. Like Arrizabalaga, about 12 percent of biology majors are members of minority groups underrepresented in the sciences. A little more than half are women—up from about 30 percent in the 1960s. Most come to college directly from high school, but some have taken time off or arrive at four-year colleges by way of two-year colleges. An increasing number of biology majors are older students who are returning to college to finish a degree or earn a second degree.

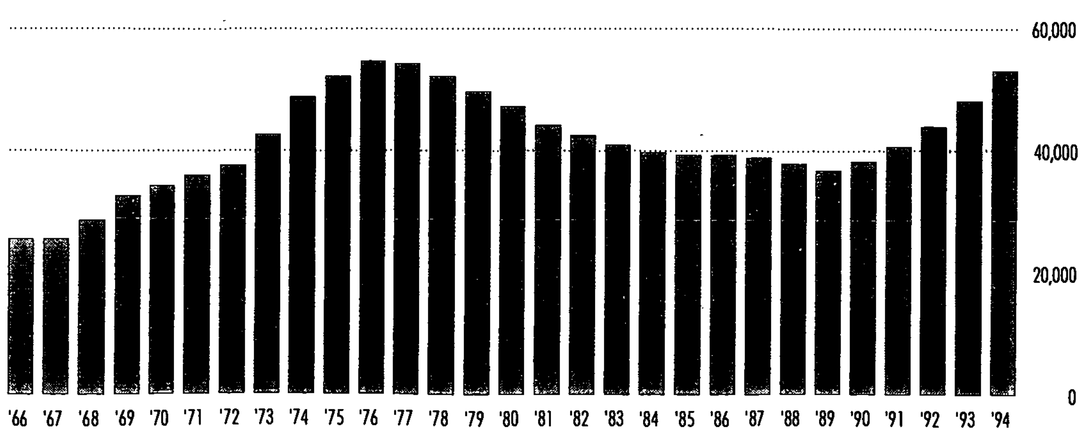
The careers for which these students are preparing are equally diverse. Nationwide, about 10 percent of biology majors go on to graduate school in biology and other sciences, and about 20 percent go on to medical school. A small but significant fraction become teachers in elementary and secondary schools. Others take jobs in industry, government, the nonprofit sector, law, journalism, and many other fields.

Beyond the core group of biology majors are millions of other college students who take one or more biology classes each year. They might be satisfying a requirement for a related undergraduate degree such as psychology, agriculture, or education. They might be fulfilling a distribution requirement with a science perceived to be less mathematically oriented than physics or chemistry. Or maybe they are studying biology to learn more about themselves and the world around them.

Whatever their motivation, they are taking part in an experience that is undergoing decisive change. The number of students taking biology classes has soared in recent years, even though budgets in many biology departments have stayed level or declined.

Bachelor's Degrees in the Biological Sciences

Year of Degree Award
('94=1993–94)



Source: U.S. Department of Education

Class sizes have increased, competition for research experiences has intensified, and faculty members have searched for new ways to deliver a quality education to an increasingly diverse group of students.

At the same time, the job market for students with biologically oriented educations has been shifting. Medical schools and biology graduate schools are reexamining their curricula and enrollment levels in the face of managed care, fierce competition for academic jobs, and other pressures. Positions in industry continue to be available, but downsizing in both the public and the private sectors has generated considerable uncertainty. Students are intensely focused on what education can do for their careers.

Less utilitarian forces also are at work. After a century in which engineering and the physical sciences dominated public attention, many of the most pressing issues in the 21st century are likely to have biological roots: preventing and treating formidable illnesses like AIDS, feeding a rapidly expanding world population, developing biological sources of materials and energy. Biology is attracting students in the same way physics did in the 1950s and 1960s—because it is at the leading edge of intellectual activity today. "It's what students read about in the newspaper all the time," says biologist Bruce Alberts, president of the National Academy of Sciences.

Furthermore, biology seems on the verge of answering some of the most tantalizing questions in science: How do organisms grow and develop? How do ecosystems function? To what extent can and should we manipulate the biological world? And these questions are not far removed from the world of undergraduates. College students are cloning genes, investigating the properties of neurons, and measuring molecular evolution—activities that were limited to graduate students, postdocs, and professors just a few years ago.

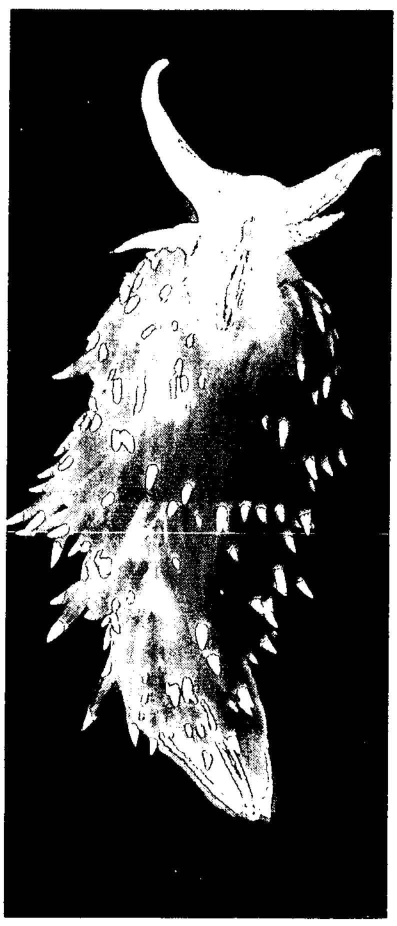
Changes in enrollments and the economy have raised a host of complex issues for faculty. As the percentages of students accepted into medical school and graduate school decline, the needs of students going into other careers have become more prominent. Biology faculty members are asking how biology can serve as the core of a strong liberal arts education, preparing students for a wide range of ever-changing careers. And they are reexamining whether their courses for non-majors adequately prepare students for citizenship in a democracy that depends increasingly on science and technology.

These issues are contributing to a growing ferment in undergraduate biology education. Professors are experimenting with ways to engage students more actively in learning, even in the large classes that result from growing enrollments. Laboratory experiences are turning into open-ended investigations in which students learn not only how to operate microscopes and centrifuges but also how to design experiments, solve problems, and communicate their results. Students are getting involved in research projects even as freshmen and sophomores. And everywhere—in dorm rooms, libraries, laboratories, and classrooms—new technologies are redefining science education.

These new approaches are raising tough questions. How can instructors create meaningful hands-on experiences for large numbers of students? Can undergraduate education combine such experiences with the breadth of coverage that a rapidly expanding knowledge base seems to demand? Should biology classes focus primarily on the content or the process of biology? How can effective teaching be disseminated more widely?

This publication examines these questions through the experiences of many of the more than 200 colleges and universities that have received grants from the Howard

Biology is attracting students in the same way that physics did in the 1950s and 1960s—because it is at the leading edge of intellectual activity today.



***Hermissenda Crassicornis*, or sea slug, a nudibranch mollusc.**

Hughes Medical Institute to strengthen their undergraduate biology programs. By describing what is going on in classrooms and laboratories around the country, it seeks to examine and contribute to the changes now under way.

This first chapter looks at how diverse institutions are dealing with the squeeze caused by rising enrollments and constrained budgets. Succeeding chapters examine curriculum reform efforts, innovative biology laboratories, competing demands on faculty members, and ways to broaden access for women, underrepresented minorities, and non-traditional students. A final chapter asks how to make improvements in biology education an institutional imperative that involves all aspects of the undergraduate experience.

DOING MORE WITH LESS

For many biology departments, the squeeze between enrollments and resources has been the single most pressing issue of recent years. Between 1989 and 1994, the number of biology majors rose by more than a quarter—and total enrollments in biology courses rose even faster. Yet many colleges and universities, especially public institutions, have seen flat or declining resources.

INSTITUTIONAL PROFILE
University of Illinois at Urbana-Champaign (1995–96)

Classification: **Public research university**
Campus: **Town**
Undergraduate enrollment: **26,700**
Graduate enrollment: **9,800**
Total biology majors: **2,095**
1995 bachelor's degrees awarded from School of Life Sciences: **366**
Faculty in School of Life Sciences: **71**

Interest in medical careers accounts for part of the enrollment increases, although it is difficult to tease out the exact contribution or the impact of recent changes in the health care system. About half of the 16,000 or so students who enter U.S. medical schools each year have undergraduate degrees in biology. When the economy turned sour toward the end of the 1980s, more and more students began applying to medical school, which in turn drove up biology enrollments.

The experiences of the University of Illinois at Urbana-Champaign are typical. Set in the central Illinois prairie, the university has a reputation for preparing talented Illinois students for careers in medicine. More than a third of its biology majors apply to medical school, and physicians' offices across the state feature Illinois diplomas.

When interest in medicine headed up in the late 1980s, the number of biology majors at the university exploded. "We're now in the unusual position of trying to control enrollments," says Edward Brown, associate professor and associate director of academic affairs in the School of Life Sciences, the university's equivalent of a biology department. The university has raised admissions requirements for incoming students applying to enter the School of Life Sciences. And it has placed a $500 surcharge on annual tuition for life sciences majors to defray the costs of laboratories and computers. "The resources we need to commit to the program are staggering," says Brown.

At the same time, the number of faculty positions at the School of Life Sciences has been level or slightly decreasing as the Illinois state legislature has limited funding for higher education. As a result, class sizes have climbed steadily. "Even our small classes have grown in size," says Sondra Lazarowitz, professor of microbiology. "In general, I would say that our popular upper-level classes have more or less doubled in size."

At some institutions, the response to swelling enrollments might be to make courses tougher so that students will drop out, adding to an already serious problem of attrition in biology. As sociologists Elaine Seymour and Nancy Hewitt note in their report *Talking About Leaving: Factors Contributing to High Attrition Rates Among Science, Mathematics, and Engineering Undergraduate Majors* (Boulder: University of Colorado, 1994), more than half of the freshmen who intend to major in biology switch to other majors before graduation.

Biology faculty members at the University of Illinois have worked hard to avoid such losses. "It's an issue of how you see your job," Lazarowitz says. "When students

ROSETTA DALTON

As an undergraduate biology major at the University of Illinois, Rosetta Dalton hoped to become a conservation biologist. But now she's training to put biology to work in another way: as a high school teacher.

Dalton graduated from Illinois in 1990 and spent the next several years raising her daughter and working at assorted jobs. Eventually she re-enrolled at the university in a master's program in biology, where she took a course on teaching. That changed her career plans entirely.

"I loved teaching," she recalls. "I realized that this is what I should be doing." Dalton switched to a master's program in biology teaching and plans to begin teaching the subject somewhere in Illinois after she graduates.

Learning biology from the perspective of a teacher has been a different kind of experience, according to Dalton. "I feel as if I'm learning it all over again," she says. "In college there are still many classes where you can get by with memorizing. I want to be a different kind of teacher. I want my students to know what's going on, not just memorize things."

The University of Illinois at Urbana–Champaign has taken a number of steps to respond to growing student interest in biology, says professor Sondra Lazarowitz.

are admitted into the School of Life Sciences, we think that they have the potential to make it. Our job is not to haze students so that only a small percentage make it through. Our job is to see that they succeed and get a good college education." Their efforts are paying-off: attrition in the School of Life Sciences is minimal, and more students transfer into the school each year than out.

One way the school emphasizes retention is through the allocation of resources. In the undergraduate research program, for example, a portion of the resources go to students at risk of leaving biology. "We particularly want to reach out to students who have a tendency to fall through the cracks, including women and minorities," says Lazarowitz.

Curriculum reforms also have proved important. At the beginning of the 1990s, for example, the school revamped its introductory biology sequence. "The old sequence was getting very out of date," says Melissa Michael, one of the laboratory coordinators for the new sequence. "We decided that the life cycle of the liverwort just wasn't that relevant for today's students."

Highlights of the revamped sequence are new laboratories that try to introduce students to how biologists really do research. Each semester, for example, as many as 700 students do hands-on experiments such as running DNA samples on gels, working with transgenic organisms, and conducting ecology experiments on field trips.

Having such large numbers of students do real experiments has made for huge logistical difficulties. "Running gels for 700 students is not something, as far as we know, that has ever been tried anywhere else," says Michael. Yet the logistical challenges have reinforced an important message that the new lab is trying to convey. "It's hard to teach students that science doesn't always work," according to Michael."They resist that like fire."

The University of Illinois also has sought to use technology to counteract the depersonalization of large courses. Students can send questions by electronic mail to professors and teaching assistants at any time of the day or night, and replies often come back immediately from instructors working on the network. Homework goes out over the network, and students compare notes with instructors and each other to get assignments done. "Computers by themselves are boring," says Roy Roper, coordinator of the computer network in the School of Life Sciences. "What we're doing is creating communities of people who might not even have known that they wanted to belong to such a community."

The combination of new technologies, new laboratories, and new courses has enabled Illinois to keep pace with growing numbers of biology students. But will the pressure eventually ease? Most faculty members think not. Even if graduate school enrollments contract and interest in medicine drops because of changes in the nation's health care system, many professors believe that enrollments in biology will remain high. "I don't think these enrollment increases are just a fad," says Donald Ort, professor and interim director of the School of Life Sciences. "I think biology is the science of not just this decade but of the next few decades. And it's more than just new jobs. It's the impact of biology on society in general."

TURNING STUDENTS INTO SCIENTISTS

Some biology departments are more insulated from the ups and downs of funding. At Reed College—a small liberal arts college in a quiet suburb of Portland, Oregon—resources for biology have grown gradually over the past decade, and the size of the department has increased from eight to ten faculty members. But the department has had to deal with the same inexorable rise in enrollments—up almost 70 percent since 1986.

Many of these students are interested in medicine, but Reed also has a strong tradition of sending students to

INSTITUTIONAL PROFILE

Reed College (1995–96)

Classification: **Private liberal arts college**

Campus: **Suburban**

Undergraduate enrollment: **1,276**

Graduate enrollment: **14**

Total biology majors: **171**

1995 bachelor's degrees in biology: **43**

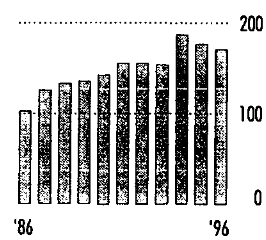
Faculty in biology department: **10**

JAN LIPHARDT

Reed senior Jan Liphardt has always felt torn between biology and the social sciences. "I grew up in different countries because my family moved around a lot, and I've always been interested in history and languages." Liphardt started Reed as a political philosophy major, choosing the college after meeting some Reed students in Paris. But the summer after his first year he took an introductory biology class at Harvard and returned to Portland as a biology major.

A few months later Liphardt began to research viral packaging in yeast, a topic that intrigued him and eventually became the focus of his senior research project. Still, he studied a wide range of subjects at Reed and, until recently, considered law as a possible career. However, an offer to continue his biology research as a graduate student at Cambridge University proved too good to turn down.

Liphardt continues to think about ways to bridge biology and law. "In Europe a patent lawyer is both a scientist and a lawyer," he explains. "I hope to get my Ph.D. first and then study law."



Number of Declared Biology Majors at Reed College

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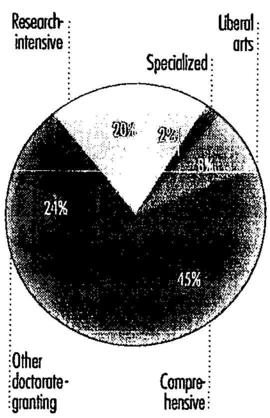
Reed College student Katherine Deland (left) and faculty advisor Maryanne McClellan are working together on a study of genetically programmed cell death.

The Baccalaureate Origins of Ph.D. Biologists

What kinds of undergraduate institutions are most likely to produce graduates who go on to earn doctorates in biology? Research universities and liberal arts colleges produce the most per capita. But other doctorate-granting institutions and comprehensive institutions also graduate sizable numbers of future biology Ph.D.s.

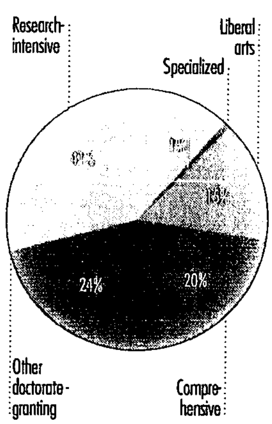
According to an analysis by the National Science Foundation, 41 percent of the people who received their biology Ph.D.s in a recent five-year period earned their bachelor's degrees from 70 leading research-intensive colleges. Next were other doctorate-granting institutions, comprehensive institutions, liberal arts colleges, and specialized institutions (such as engineering schools and military academies). Liberal arts colleges accounted for only 8 percent of the undergraduates in four-year colleges and universities but for nearly twice as many of the eventual Ph.D.s.

The same study revealed the special importance of several types of institutions. Among African Americans who earned Ph.D.s in the biological sciences, for instance, 42 percent attended historically black colleges and universities as undergraduates. Also, of the 12,334 people who received biology doctorates between 1987 and 1990, 1,073, or 9 percent, began their undergraduate education at two-year colleges.



Type of Institution Attended by Students at Four-Year Colleges or Universities

Because of rounding, totals do not add to 100.



Type of Institution Attended as Undergraduates by Biology Ph.D.s

Because of rounding, totals do not add to 100.

Source: National Science Foundation, "Undergraduate Origins of Recent Science and Engineering Doctorate Recipients" (Washington, D.C., 1992).

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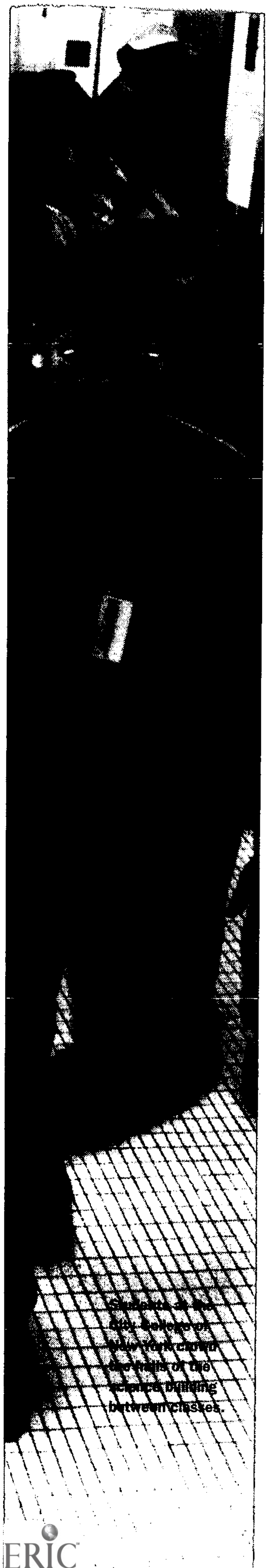


Students at the City College of New York crowd the halls of the science building between classes.

graduate school in biology. Among the 1,100 biology graduates for which the college has survey data—representing virtually all of its living biology graduates—almost 200 have Ph.D.s, a much higher percentage than at most colleges and universities.

Reed's success in generating biologists reflects its commitment to undergraduate research. At the end of their junior year, students at Reed must pass a qualifying exam to be admitted as seniors in the department of their declared major. All students must then complete an original research thesis to receive their degrees.

As enrollments have swelled, requiring every student to do research has often meant accommodating five or six undergraduates in a single lab. Yet faculty members remain committed to the requirement, despite the strain on budgets and time. "The immediacy of the connection between students and faculty is critical in getting them to think like scientists," says professor Stephen Arch, who chairs the biology department. "That's why we have so many students who go on to graduate school."

Many other aspects of biology at Reed contribute to its research-rich environment. Students can apply for minigrants of up to $1,500 to pursue an interesting idea. At the end of their projects, they write up the results and present them to a thesis committee and at a department-wide scientific meeting. "The focus is on evaluating the literature, picking hypotheses, and testing them," says professor Maryanne McClellan. "We're trying to make students into good researchers."

Most biology students agree that research is the highlight of their time at Reed, despite the rigors that senior projects can entail. "The faculty are so involved, the students are so involved. It's tremendously rewarding," says student Katherine Deland, who did research with McClellan on the impact of steroid hormones on genetically programmed cell death. Hired for a year after graduation to continue her research in McClellan's laboratory, Deland is now looking to combine a law degree with a master's in public health. "I'll still be using my biology degree, but in a different way," she says.

PREPARING FOR SUCCESS

Three thousand miles away, undergraduate research is also emphasized at City College of the City University of New York, where more than half the biology majors do research before they graduate. But research is just one of the ways in which City College faculty members seek superior performance from their students.

Perched on a ridge in the western part of Harlem, City College has a student body that reflects the young and immigrant population of New York City. Over 82 percent of the students are African American, Hispanic, or Asian, and students on campus speak more than 100 languages. Since the late 1960s, the City University of New York, of which City College is a part, has had an open admissions policy, with every high school graduate from New York City guaranteed a spot at one of the system's campuses. As a result, many students who arrive at City College need extra help to excel at biology.

INSTITUTIONAL PROFILE
City College of New York (1995–96)
Classification: **Research university**
Campus: **Urban**
Undergraduate enrollment: **10,686**
Graduate enrollment: **3,471**
Total biology majors: **258**
1995 bachelor's degrees in biology: **45**
Faculty in biology department: **25**

Biology faculty members at City College have taken a number of steps to meet the needs of their students—despite a sharp reduction in the number of faculty members because of state budget cuts. Incoming freshmen interested in biology can attend a four-week summer program to prepare them for introductory courses and laboratories. Students about to enter sophomore-level biology, where attrition is often high, can attend a two-week preparatory course in the summer. Outreach programs to Manhattan high schools help potential City College students get ready. "Many of these students have no idea what college is like," says Millie Roth, director of the City College Academy for Professional Preparation, which offers academic support and enrichment activities to science students. "They're the first in their families to go to college, so they can't call on people they know to tell them what's going on."

The highlight of City College's efforts to retain students in the sciences is its Program for Access to Science Study, or PASS, class. Each year as many as 100 freshmen and sophomores enroll in an introductory class to learn the skills they need to progress in science. In addition to attending conventional lectures and laboratories, the students meet with counselors in small groups each week to discuss time management, goal setting, and test taking.

In a recent PASS class on the twelfth floor of City College's science building, two dozen students discussed what it means to be successful. One by one they stood in front of the class and described how they hope to achieve their goals. Many talked about wanting to become doctors and moving their families from unsafe neighborhoods. Others talked about just getting through a class, or reaching the end of the semester, or getting a driver's license so they could avoid dangerous subway rides. They talked about their pride in attending college and about the decisions that led them to City College.

These PASS students include those expected to have the greatest difficulties at City College. Yet their retention rates have been substantially higher than for the college as a whole. "It's really very rewarding to have these students, because they come from parts of society where they don't necessarily get a boost, but they're highly motivated," says biology professor Olivia McKenna.

City College also tries to give special support to juniors and seniors, often by involving them in research. For some the experience can change their lives. Steve Caddle, for example, was headed nowhere as a high school student in New York City. "I goofed around a lot and ended up staying in high school an extra year," he says. "That's when I woke up and decided I could be moving on to bigger and better things."

He enrolled at New York City Technical College, where he spent two years "trying to figure out what to do with my life." Then he transferred to City College, where he excelled in science courses and began to do work in the laboratory on the effects of insulin-like growth factor on cells. An internship at Roosevelt Hospital got him interested in medicine, and in his senior year Caddle won the Jonas Salk award, a city-wide honor for students doing undergraduate research. Today, he is a medical student at Albert Einstein Medical School in the Bronx, near where he grew up.

As James Traub points out in his book *City on a Hill: Testing the American Dream at City College* (New York: Addison-Wesley, 1994), many City College students do not complete their college educations. Only about 30 percent of those who enroll earn degrees, although a significant number eventually earn their degrees elsewhere. But for those like Steve Caddle with the perseverance needed to excel, City College remains a door to opportunity.

COMMON THEMES AMID DIVERSITY

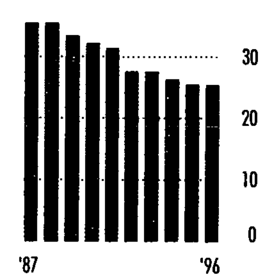
It's not easy to find three institutions more different than the University of Illinois at Urbana-Champaign, Reed College, and City College. But all share a fundamental commitment to recruiting and retaining students in the biological sciences. And all have implemented that commitment in ways that reflect their own circumstances.

This publication looks at many other institutions that have found their own ways to serve the needs of students. Their approaches are similarly diverse. Yet as the remaining chapters of this book illustrate, they are linked by shared themes. Just as Gustavo Arrizabalaga found his calling in genetics and Sharon Brooks turned from Broadway to biology, colleges and universities across the country are traveling many paths toward a common horizon.

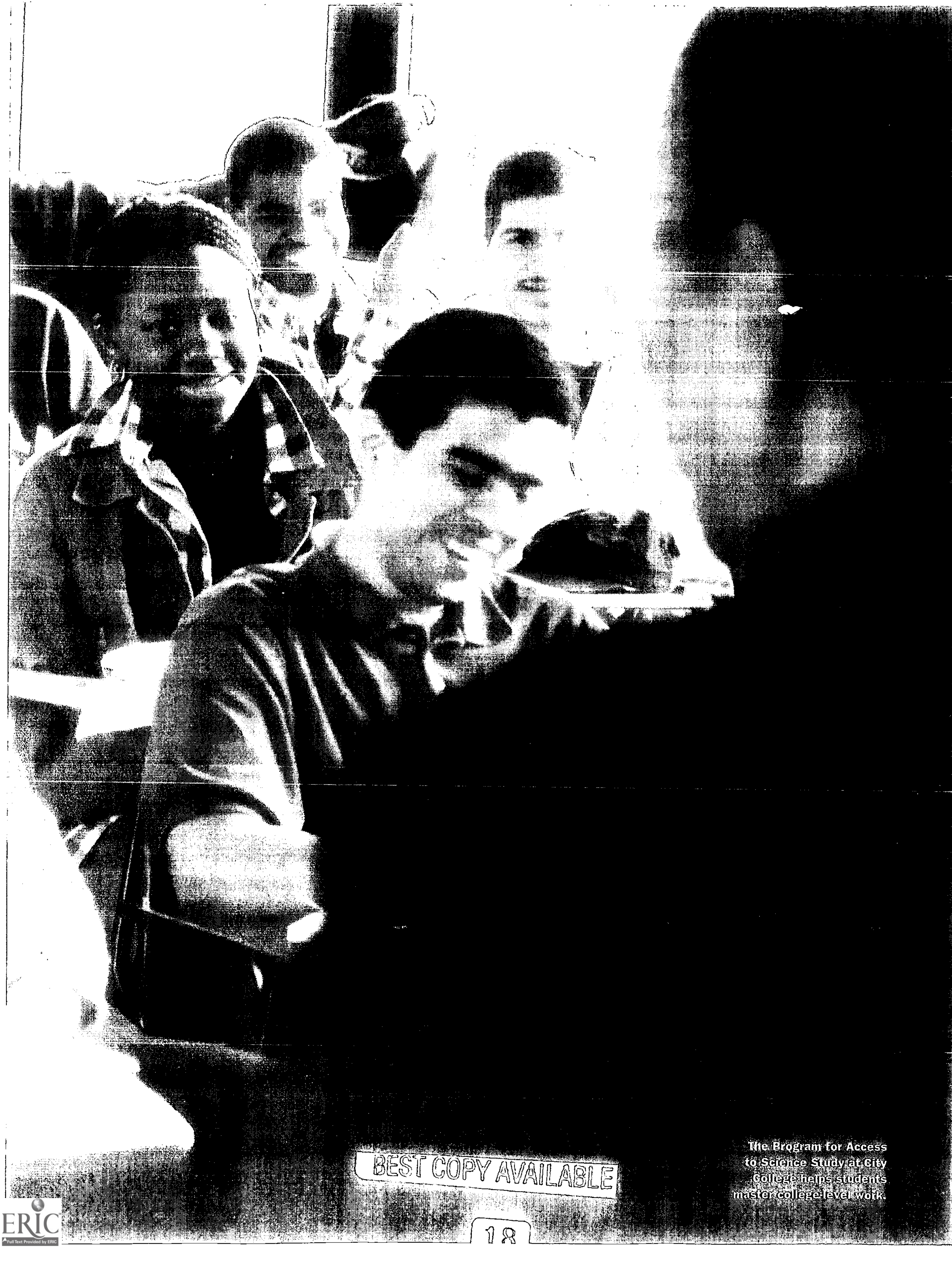
SHARON BROOKS

The lights of Broadway pale beside the promise of biology for Sharon Brooks. A successful singer and dancer in New York City, Brooks yearned for something else. "I knew I wanted to be a doctor, but I didn't have any idea how to do it," she says. She finally enrolled at City College in her late 30s and began studying biology. For the past several years, she has been going to school during the week and flying to various U.S. cities on the weekends working with entertainer Gregory Hines as a vocalist.

Knowing that the transition to college would be difficult, Brooks enrolled in the Program for Access to Science Study to get up to speed. "If I hadn't taken PASS my first year, I wouldn't have gone on," she says. "That was the class where I was testing myself to see if I could make it." Now completing her requirements in organic chemistry, she is preparing to apply to medical school.



Number of Biology Faculty at City College of New York


The Program for Access
to Science Study at City
College helps students
master college-level work.

Reaching Out to Biology Teachers

Undergraduate biology begins not with cells or genetics but with something even more complicated: elementary and secondary school.

College professors have complained for years about the poor preparation of many of the students who emerge from high school science and mathematics classes. But high school teachers often respond that they are constrained by a heavy course load, minimal resources, and inflexible curricula. Instead of blaming us, they say, why don't universities help us?

A growing number of institutions are trying to do just that.

At the University of Colorado at Boulder, high school and middle school teachers can take Saturday workshops filled with practical ideas for bringing biology class to life. A workshop entitled "Rainbow Electrophoresis," for example, attracts 16 teachers who learn low-cost methods of introducing students to the concept of DNA electrophoresis. Instead of using purified agarose from a biology supply company, the teachers whip up gels with agar flakes and bars from a natural foods store.

"We've gotten the cost down to 15 cents per gel," says Louisa Stark, a campus scientist-in-residence and workshop organizer. Similarly, the teachers form patterns in the gels with food coloring instead of DNA, trading biological precision for a quick, colorful, and inexpensive lesson.

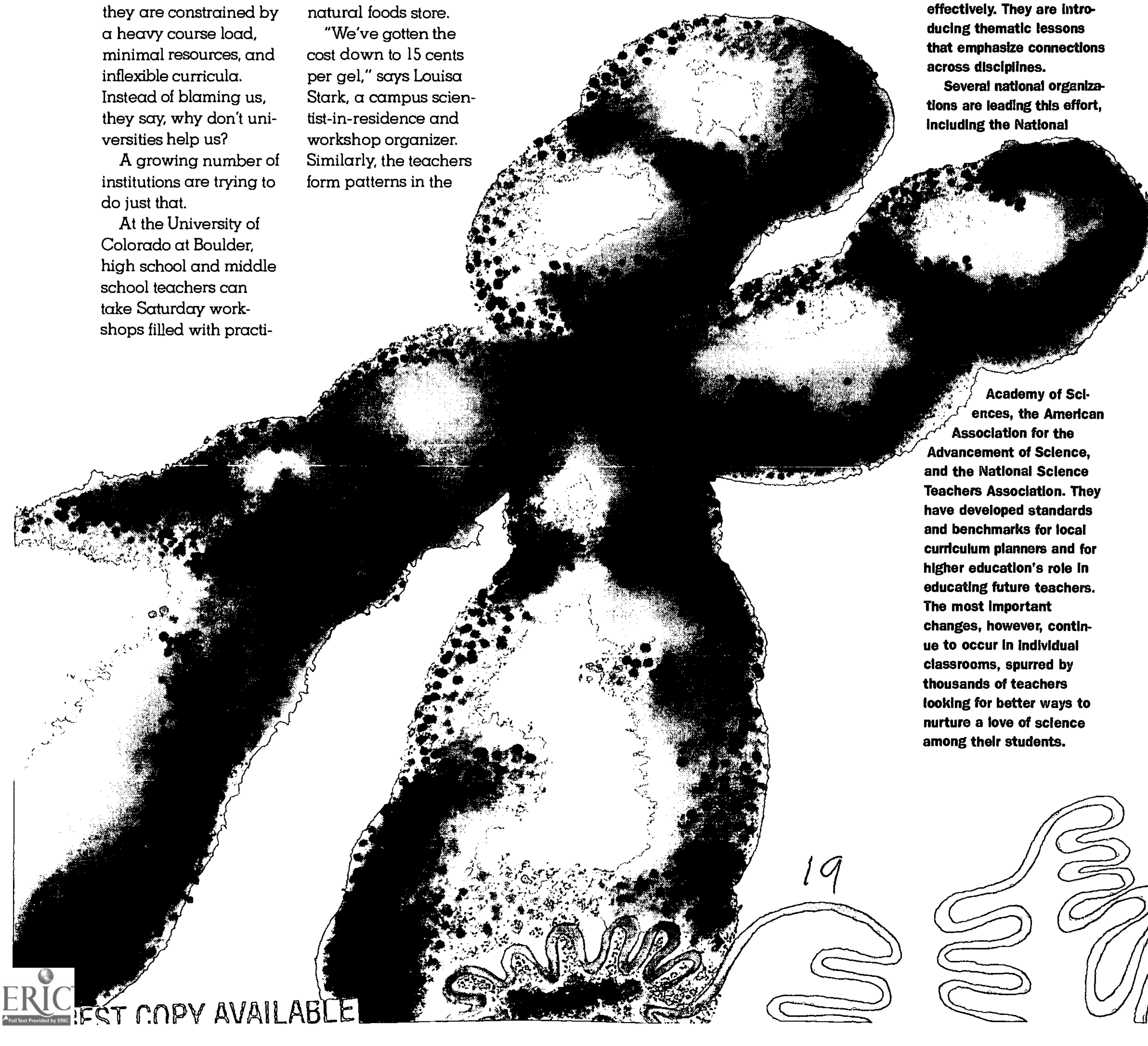
Another workshop focuses on microbiology, while a third uses paper making to teach high school students about botany, chemistry, and other subjects. In each case the goal is to provide teachers with workable techniques to take back to their schools.

"Until kids actually manipulate the materials and do it themselves, they doubt what you're teaching them," says Tammie Meyer, a teacher at Boulder High School who participated in a recent workshop. "They learn ten times more this way."

BIG CHANGES IN HIGH SCHOOL BIOLOGY

Many of the changes under way in undergraduate biology classes also are taking place at elementary and secondary schools. There is a growing emphasis on helping students master the processes of science—such as forming hypotheses and evaluating data—as well as mastering a fundamental body of knowledge. Schools are challenging students to reason and communicate effectively. They are introducing thematic lessons that emphasize connections across disciplines.

Several national organizations are leading this effort, including the National Academy of Sciences, the American Association for the Advancement of Science, and the National Science Teachers Association. They have developed standards and benchmarks for local curriculum planners and for higher education's role in educating future teachers. The most important changes, however, continue to occur in individual classrooms, spurred by thousands of teachers looking for better ways to nurture a love of science among their students.



The workshops, free to teachers, are only one way the university is assisting local schools. Both graduate students and faculty members from a campus "Science Squad" visit local classrooms to carry out demonstrations and interact with students, many of whom have never met a scientist before. Squad member Jorge Moreno, who was chief of wildlife resources in Puerto Rico before earning his doctorate at the University of Colorado, tells classes about the biological techniques he used to protect endangered species. Velia Mitro, a graduate student in biochemistry, helps young students compare the enzymatic action of different laundry detergents on the proteins in gelatin.

Another initiative brings students from two inner-city schools to Boulder for weekend bioscience workshops and to learn about campus life. Undergraduates from the campus volunteer in Denver schools through a science partnership program.

During the summer, high school biology teachers take special academic courses on campus and work on research projects with university scientists. They also can apply to the university for grants of up to $500 to develop or purchase materials for their classrooms. Joseph Figlino of St. Anne's Episcopal School in Denver received a grant to design a computer program in which students evaluate medical clues to diagnose the illnesses of imaginary patients. Linda Libby of Chatfield High School in Littleton, a school district where "a lot of families don't believe in evolution," got a grant to expand her classroom collection of primate skulls, providing students with new resources to help them reach their own conclusions.

Scientist-in-residence Louisa Stark leads a Saturday workshop at the University of Colorado at Boulder for science teachers from local high schools and middle schools.

The University of Colorado is not alone in trying to strengthen ties with local science teachers. On the same day teachers gathered in Boulder for the electrophoresis workshop, for example, Texas Tech University sponsored a regional conference where elementary and secondary school teachers in the Lubbock area explored hands-on methods for teaching students about animal behavior, electron microscopy, and more than 25 other topics. Cornell University manages a computer discussion group where high school biology teachers swap ideas via modem. Gettysburg College sends a "science van" with modern scientific equipment to nearby schools. Rice University runs a teacher resource center.

Teachers involved in these programs agree that the experiences renew their enthusiasm for science and enhance their effectiveness in the classroom. It also helps their students to put a human face on the scientific enterprise. "When the Science Squad visits my classroom, they really take the mystery out of science," says Boulder teacher Tammie Meyer. "It's empowering for my students. They say, 'Hey, I can do this.'"

WHERE DO THEY FIND THE TIME OR MONEY?

Many biology professors are enthusiastic about assisting local teachers but have limited time and resources to manage the logistics.

At the University of Colorado at Boulder, the vice chancellor's office has created an institutional structure that leaves professors free to concentrate on instruction. A former science teacher, Julie Graf, coordinates the biology outreach programs and identifies opportunities for participation by professors as well as undergraduates, graduate students, postdoctoral fellows, and research associates. Graf also works closely with local teachers, often incorporating their suggestions into new programs. At Washington University in St. Louis, former middle and high school science teacher Elaine Alexander plays a similar role, as do coordinators elsewhere.

Such support systems make it easier to "use everyone's talents efficiently," Graf says, but they require additional resources. "Financially it's hard for the university to take care of its undergraduates, even before sharing the pie with the K–12 community," says Graf, who is concerned about what will happen to outreach programs at the University of Colorado and elsewhere if financial pressures intensify.

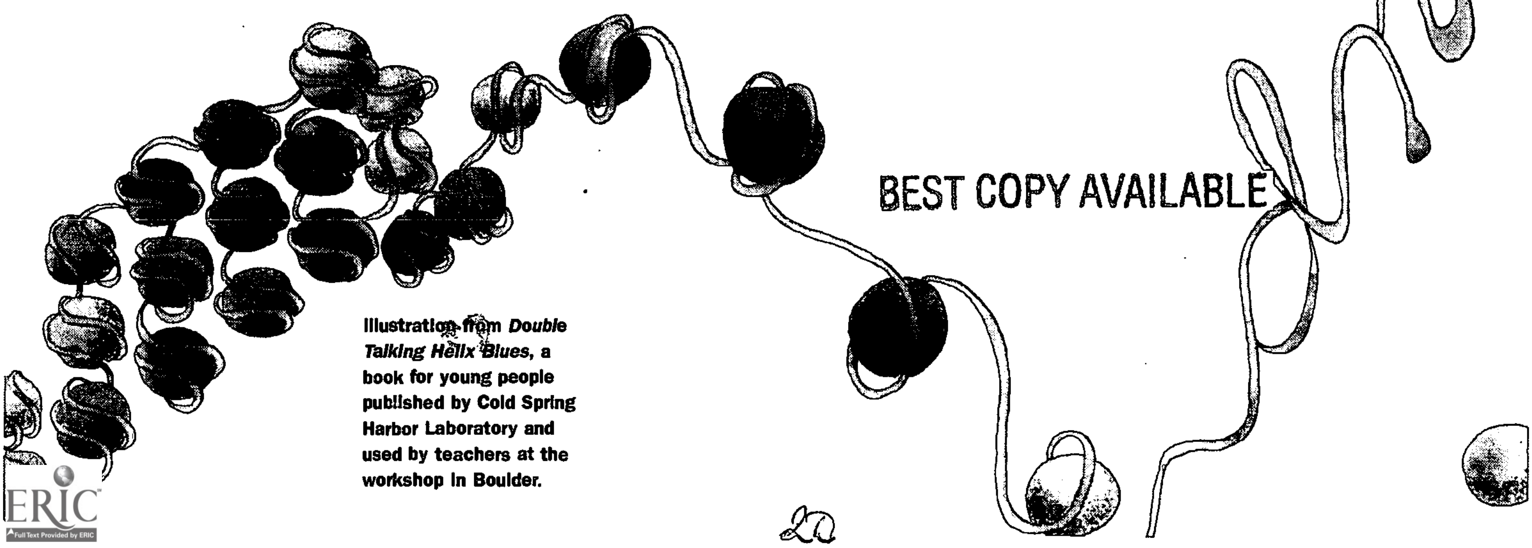


Illustration from *Double Talking Helix Blues*, a book for young people published by Cold Spring Harbor Laboratory and used by teachers at the workshop in Boulder.

BEST COPY AVAILABLE

Throughout the large lecture hall, clusters of students are arguing, gesturing, and jotting down notes. At the lectern, professor Jo Handelsman waits quietly for the commotion to subside. The beginning of class? No, this *is* the class, and the way it is being taught points toward an important new emphasis in biology education: a focus on not only what students know but how they think.

For the past several years, Handelsman, a plant pathologist at the University of Wisconsin–Madison, has been teaching all of her classes in an interactive style. After a brief introduction to the day's topic, she jots down a question or issue on the board. She then has the students in the lecture hall break into small groups and discuss the question among themselves. After a few minutes she calls the class back to order and has the groups briefly present their ideas, which she jots on the board. "It's so simple, but it's the most powerful learning technique I've used," she says.

CHAPTER 2

CHANGES IN THE CLASSROOM

University of Wisconsin–Madison professor Jo Handelsman guides her students through classroom exercises.

Handelsman's approach is one of a number of innovative teaching techniques that are finding their way into biology departments. Some rely on the ability of students to work together and teach each other. Others use new information technologies to encourage interactive learning and foster the development of learning communities. The common theme is to move beyond the passive learning that characterizes lectures toward more active, engaged forms of learning.

"We tend to teach the sciences badly now," says John Moore, professor emeritus of biology at the University of California–Riverside and author of the series *Science as a Way of Knowing* (which originally appeared in the journal *American Zoologist* and recently has been reprinted by Harvard University Press). "We overemphasize facts without providing a conceptual framework for the science. We convey more information than understanding. For science to be liberating, it has to be understood, not just memorized."

GETTING STUDENTS INVOLVED IN LEARNING

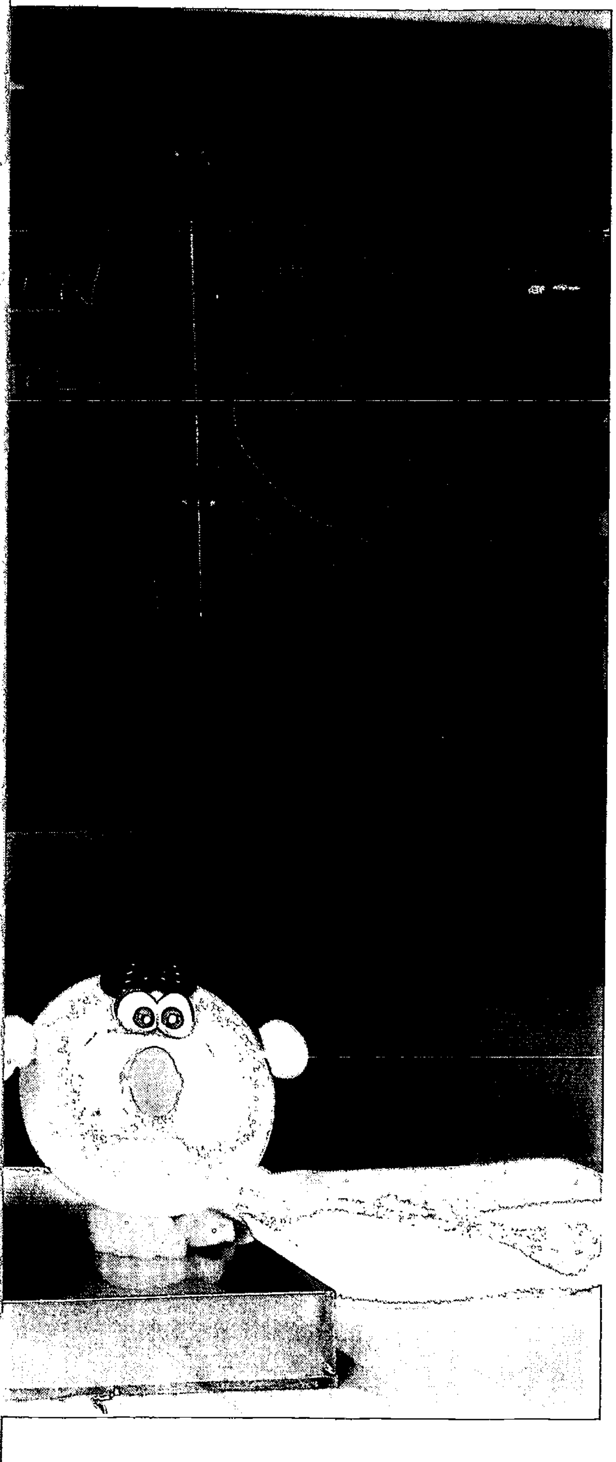
When Handelsman began teaching at Wisconsin ten years ago, innovative teaching methods were the furthest thing from her mind. In the rush to set up her own laboratory and apply for grants, she did what most new faculty members do: teach the same way she had been taught.

Three events transformed Handelsman's thinking about teaching. The first was when she brought a sick plant to an introductory course for non-majors and asked the students to design and conduct simple experiments to determine the cause of the symptoms. "The classroom was buzzing with discussion," Handelsman says. "It was a very crude exercise, but it made me see for the first time the enthusiasm these non-majors had for science."

The second was when, at a friend's suggestion, she moved away from lecturing toward more active forms of teaching. In her classes she broke students into groups and had them discuss possible causes of plant diseases, which she then gathered from the groups. "The results were stunning," she recounts in her recent book, *Biology Brought to Life* (Dubuque, Iowa: William C. Brown, 1996), cowritten with Barbara Houser and Helaine Kriegel. "First, the students' list of possible causes was longer than the list in the lecturer's notes. Second, some of the most creative ideas were from students who had never before spoken in class and from some who had done poorly on exams. Third, during the rest of the lecture the students asked many more questions and seemed more interested than usual. This got us thinking about what we were missing with the exclusive use of the lecture."

The third turning point came from working with a bright, diligent student who consistently failed exams. One day, in an attempt to figure out what was wrong, a colleague of Handelsman's asked to see the student's notes from that day's class. The student had written only three lines during a 50-minute lecture. So Handelsman began to incorporate more

In his introductory neuroscience course at Brown University, HHMI investigator Mark Bear performs "brain surgery" on melons to demonstrate the anatomical planes of section—with students and instructor eating the results when the lecture is over.



explicit guidance in her classes about the skills needed for success in college science courses.

She developed these techniques in a class for non-majors entitled "Plants, Parasites, and People," and what she calls "turning the curriculum on its head" remains the goal of much of her teaching. "The people we should be teaching about how to design experiments and actually do science are freshmen, and especially non-majors," she says. "What we've been trying to do is bring the processes of science in a rigorous way to the freshman level. Students walk away with a sense of what science is because they've been scientists for a semester."

At the same time, Handelsman has been using innovative teaching techniques increasingly in her classes for majors—sometimes in rooms with 200 to 300 students. "It's harder with 250 students, but it's do-able," she says. "And it's really the most rewarding with majors because you can use the hardest biological problems with them and they respond." Handelsman might describe the characteristics of a particular bacterium and then ask the students to come up with strategies that researchers could pursue, for example, in creating antibiotics to block the cell's function. "Right there in class they come up with most of the things that the big pharmaceutical companies are doing."

The most common objection to active learning techniques is that classes cannot cover as much material as traditional lectures. Handelsman disagrees. Lectures in her course might be somewhat less comprehensive, she says, but students do a better job of reading and retaining the material in textbooks and handouts because they are more motivated.

Handelsman also insists that students get much more out of her classes than just a compilation of facts. They get the reasoning skills needed to acquire and apply new information throughout their lives. "What we try to do is build a scaffolding so that students can hang new information on it," she says. "If the scaffolding isn't there, what we teach them or what they try to learn later can't stick."

Handelsman emphasizes in addition that her objectives are emotional as well as intellectual. She tries to create a learning environ-

Active Learning Strategies

Faculty members have developed a wide array of techniques to get students more actively engaged in learning. Following are a few examples drawn in part from the books *Active Learning: Creating Excitement in the Classroom*, by Charles C. Bonwell and James A. Eison (Washington, D.C.: The George Washington University, 1991), and *Teaching Tips: Strategies, Research, and Theory for College and University Teachers*, 9th edition, by Wilbert J. McKeachie (Lexington, Mass.: D. C. Heath, 1994):

- **Students write a "one-minute paper" at the end of a lecture summarizing its points or listing concepts they did not understand.**
- **Students lead discussion groups with faculty guidance.**
- **Student volunteers hold a mini-discussion section with the instructor in a special area of the lecture hall while other class members watch.**
- **Students record and turn in a "reading log" where they reflect upon course-related materials they have read.**
- **One student takes minutes of a class and reads them at the beginning of the next class.**
- **Groups of students cooperate on a short quiz part way through a lecture.**

"For science to be liberating, it has to be understood, not just memorized."

ment in which everyone is welcome and respected, where students are part of a community that offers support to all. "I skipped a lot of classes last year, but I always went to hers," says student Kristin Berg, who took Handelsman's class as a freshman. "She believed in me."

THE STUDENTS' REACTION

There are many ways in which teachers can foster active learning, some as old as Socrates' pointed questioning of his pupils. An engaging, well-constructed lecture, besides being a cost-effective way of conveying information, can promote active learning, especially if it inspires students to reflect on new information and relate it to what they already know. Teaching laboratories, which are discussed in the next chapter, can be powerful learning tools. Independent student projects under faculty direction also are likely to engage students' interest.

Colleges and universities have been using all of these techniques for many years to teach students effectively. Now an increasing number of institutions are trying to integrate the most effective elements of the various approaches.

That was the goal of professor Paul Grobstein when he and other faculty members at Bryn Mawr College outside Philadelphia set out to redesign the college's introductory biology course. "When I came here seven years ago, we had a pretty conventional introductory course that tried to teach students everything there was to know about everything in biology," Grobstein says. "What I wanted was a course that taught what everyone *should* know about biology."

Paul Grobstein and his colleagues at Bryn Mawr redesigned the introductory biology courses to serve the needs of both majors and non-majors.

Grobstein and his colleagues undertook what would seem an impossible task: designing a one-semester introductory course that covered all of biology for both majors and non-majors, followed by a second one-semester course that covered all of biology again but in greater depth for students planning to continue in the subject. As described in the course syllabus, "Biology 101 is not a 'typical' science course, one in which the primary concern is to efficiently summarize a particular body of facts.... You will instead be invited to listen to, read about, work through in your mind, and contribute to an ongoing discussion of the relation between observations and ideas in biology."

It immediately became apparent that no single textbook was going to meet the needs of such a class. Introductory biology students typically learn more new vocabulary than students beginning a foreign language, which is just what Grobstein wanted to avoid. So he and his colleagues decided to do without a textbook, relying instead on articles, books held in reserve at the library, and a variety of handouts as reading materials.

They also decided that students would be expected to help teach themselves rather than being force-fed facts by a teacher. The instructors therefore adopted a relatively nondirected lecture style in which they pose questions to the students and help them work toward answers.

The response among faculty members who taught the course with Grobstein was enthusiastic. "It's so much more fun to teach a group of students who are thinking, not just sitting there waiting for the class to be over," says professor Karen Greif, who coteaches one of the two sections.

Unexpectedly, a major source of hesitation was the students themselves. "Students have

Breaking Up the Core

When University of Rhode Island zoology professor Frank Heppner and his colleagues surveyed the biology curricula of several hundred colleges a few years ago, Heppner expected to find a diversity mirroring the subject itself. He couldn't have been more wrong.

Like automobiles making their way down an assembly line, most biology majors take a standard sequence of courses to earn their degrees. Chemistry, physics, and calculus are the usual prerequisites. A one- or two-semester introductory biology course leads to electives in genetics, ecology, cell biology, or development, or a more rigorous core sequence in biology leads to advanced courses. Out of the nearly 300 programs Heppner surveyed, fewer than a dozen were trying something substantially different. The biggest surprise: small liberal arts colleges were more likely than research universities to have a research requirement.

Today's standard biology curriculum has been shaped to a remarkable degree by the most intensive reform effort ever to occur in undergraduate biology education. From 1963 to 1972 the Commission on Undergraduate Education in the Biological Sciences (CUEBS), a multimillion-dollar effort funded by the National Science Foundation, sought to transform biology education at the college level. It issued dozens of books, reports, and monographs, as well as a bimonthly newsletter. CUEBS sponsored conferences and workshops. It even funded teams of consultants to visit biology departments and help upgrade undergraduate teaching.

CUEBS Publication No. 18 was "Content of Core Curricula in Biology." Designed to bring undergraduate instruction closer to the frontiers of science, the document's recommended curriculum was based on the practices of four leading biology departments: those at Dartmouth, North Carolina State, Purdue, and Stanford. Though many biology faculty members are unaware of it, the courses they teach today owe a lot to what those four departments were doing in the mid-1960s.

One institution that is now rethinking many of the issues behind the standard biology curriculum is the University of Notre Dame in South Bend, Indiana. Faculty members from the chemistry, biology, and biochemistry departments have worked together to create a series of new courses that integrate biology and chemistry. For instance, instead of taking organic chemistry, students take bioorganic chemistry, with examples drawn largely from the biological sciences.

At the same time, faculty members within the biology department have sought to construct courses that combine levels of organization—such as a course in comparative physiology that ranges from the organismic to the cellular level. "Integrative biology is more than a buzzword," says Notre Dame biology professor John Duman. "It's designed to produce people who have the background and capacity to think in an integrated fashion and see problems and solutions that others can't."

Other departments have worked with disciplines outside biology to create a more integrated education in the sciences. "We're a small biology department, but we have a large medical school across the street and a big engineering department nearby," says professor Norman Rushforth, the biology department chair at Case Western Reserve University in Cleveland. In the neurosciences concentration offered by the department, students build robots that mimic biological behaviors and model neural networks. They are guided by both an engineering professor and a biology professor. "By drawing in faculty from other parts of the university, you can build a much richer curriculum," Rushforth observes.

Sometimes it is students who lead the drive toward a more integrated curriculum. At Haverford College outside Philadelphia, a select group of upper-division students gathers each week for an interdisciplinary seminar to discuss their research in chemistry, biology, and physics. "One of the things we've found about this program is that it greatly increases the communication among faculty in different departments," says professor Judith Owen. "Because we have two students talking each week, the students and faculty often hear about a subject outside their department."

Introductory Biology · Evolution of the Earth and Life · Biotechnology · The "New" Biology · History of Biology · Evolution · Electron Microscopy in Molecular Biology · Undergraduate Research in Biology · Evolution, Ecology, and Behavior · Immunology of Infectious Diseases and Tumors · Biological Basis of Sex Differences · Histology: The Biology of the Tissues · Cellular Physiology · Mammalian Physiology · Nutrition, Physiology, and Biochemistry of Mineral Elements · Biological Membranes and Nutrient Transfer · Molecular Mechanisms of Hormone Action · Membrane and Epithelial Transport · Acid-Base Relations · Regulation of Mitosis and the Cell Cycle · Current Concepts in Reproductive Biology · Recombinant DNA Technology and Its Applications · Basic Biochemical Methods · Survey of Cell Biology · Molecular Biology · Oncogenes and Cancer Viruses · Protein Structure and Function · Membranes and Bioenergetics · Biosynthesis of Macromolecules · Enzymes, Coenzymes, and Metabolic Regulation · The Nucleus · Plant Biochemistry · Protein-Nucleic Acid Interactions · Macromolecular Crystallography · Cancer Cell Biology · Ecology and the Environment · Evolutionary Biology · Microevolution and Macroevolution · Ornithology · Biology of Fishes · Principles of Systematics · Biology of Plant Species · Genetics · Human Genetics · Population Genetics · Molecular Aspects of Development · Molecular Evolution · Mammalian Development · Yeast Genetics · Plant Cytogenetics · The Nucleus · Pathogenic Bacteriology and Mycology · Immunology of Infectious Diseases and Tumors · Hormones and Behavior · Introduction to Sensory Systems · Developmental Neurobiology · Molecular Biology and Genetic Engineering of Plants

Tests and the Biology Curriculum

Do the Medical College Admission Tests (MCATs), the Graduate Record Examinations (GREs), and other graduate-level exams stifle biology curriculum reform efforts? Many faculty members and students think so. They insist that courses need to cover a certain amount of material to prepare students for graduate school exams.

The developers of the exams see things differently. According to John Olson, an educational consultant who has worked on the MCATs for the Association of American Medical Colleges, test makers have been "revising the amount of science versus other things that are considered important, like communication, critical thinking, and problem-solving skills." The last thorough revision of the MCATs in 1991 added essay questions and deemphasized rote memorization. "The test is designed to measure the concepts taught in the first year of science," says Olson.

The developers of the GREs also disagree that the use of their tests forces a heavy emphasis on memorization. Though the GRE subject tests, including the biology test and a new test that covers biochemistry and cellular and molecular biology, require a thorough familiarity with their fields, they still emphasize problem-solving and reasoning skills. Also, graduate schools tend to attach more importance to the GRE General Test, which measures verbal, quantitative, and analytical reasoning, than to the subject-matter tests. In a recent survey of biology graduate departments by the Graduate Record Examinations Board, which oversees the GRE program, more than 90 percent of departments said they use the GRE General Test for admission decisions, and

"When students ask me whether my course will prepare them for the GREs, I tell them to take a review course."

those departments gave it a mean importance rating of 3.3 (on a scale of 1 to 4). A total of 59 percent of the departments use the GRE Biology Test, and they ascribe it a mean importance rating of just 2.7.

Some faculty members downplay the entire issue. "When students ask me whether my course will prepare them for the GREs, I tell them to take a review course," says Orville Chapman, professor of chemistry and associate dean for educational innovation at University of California–Los Angeles. "They're not going to get a review course from me."

a whole set of expectations of what is supposed to happen in a class like this," Grobstein says. "A nondirected, interactive teaching style is not what they are expecting. What they're expecting is to sit there and write down what you tell them."

Faculty members listened to the students and modified the course accordingly. Having all seven professors in the department teach part of the class was too disruptive for faculty members and students, so the number of instructors for each section was reduced to two. All-essay tests were dropped because they were too intimidating for students and too time consuming to grade. Grobstein and his colleagues even reincorporated a textbook into the class, though they tell students explicitly that it is there as a supplement and is not intended to define the course's level or content.

The course has attracted considerable interest among students. Enrollments are up, and students at nearby colleges have been cross-registering at Bryn Mawr to take introductory biology there. Yet course evaluations have not been uniformly positive—a fairly common fate for innovative classes. "Lots of students don't like not knowing what the answer is," says senior Candice Morgan. "But that's what science is about. That course is what made me decide to major in biology rather than psychology."

"The course has been working," Grobstein concludes. "There has been much less concern among the students about grades and what they are supposed to know and much more genuine interest and interaction on a whole array of matters in biology and beyond."

COMMUNITIES OF ELECTRONIC LEARNERS

Skilled teachers have used active learning techniques for many years. But college faculty members now have access to a new set of tools that can bring engaging, individualized learning to every student's desktop. Information technologies, ranging from videotapes and laser disks to powerful computing and communications technologies, have the potential to recast the relationship between

At Vanderbilt University (right), professor James Staros and students cluster around a workstation used in the molecular biology laboratory. The University of North Dakota (far right) uses its Interactive Video Network to link classrooms at a far-flung network of colleges, including the state's five tribal colleges. Paired monitors show the instructor and remote classrooms.

teachers and students. The challenge facing colleges and universities is to ensure that this change *improves* undergraduate education.

One feature of the new technologies is their ability to provide students with huge quantities of up-to-date information. At Vanderbilt University in Nashville, instructors have incorporated digital photographs taken from various laboratory demonstrations, such as DNA gels, into a series of tutorials that students use to learn basic biological concepts. "Once we started making these tutorials, we realized that they were an extremely valuable medium," says Steve Garrison, systems analyst for the Department of Molecular Biology, "because we can update them on the fly and all students have access to them."

Electronic communications also are beginning to transform the social dynamics of college classes. At Emory University in Atlanta, for example, an e-mail and bulletin board system has given a voice to students too shy to raise their hands in class. "Sometimes the strongest participants are those who feel protected by their ability to think about what they're saying," says Patricia Marsteller, one of the developers of the system. In addition, students have used the system to increase interactions among themselves—for example, by putting their résumés with pictures on the network. "Rather than just coming to the lecture, students stay to talk with people because they've seen their résumés," Marsteller says.

Some of the educational benefits of electronic networks do not require physical proximity. At the University of North Dakota, the

RESOURCES

The **Coalition for Education in the Life Sciences** consists of professional societies dedicated to defining and promoting improved literacy in the biological sciences. Address: Center for Biology Education, University of Wisconsin, 425 N. Henry Mall, Room 1271, Madison, WI 53706. Telephone: (608) 265-3003. Internet: tongl@macc.wisc.edu.

The **Committee on Undergraduate Science Education** of the National Research Council has developed an extensive database containing information about model science courses, national organizations and programs involved in undergraduate science education, and summaries of research dealing with science education and pedagogy. CUSE also is establishing guidelines for improving the quality, access, and use of software in undergraduate science instruction. Address: 2101 Constitution Ave., N.W., Washington, DC 20418. Telephone: (202) 334-1462. Internet: cuse@nas.edu. World Wide Web: http://www2.nas.edu/cusehome/index.html.

Project Kaleidoscope is a national alliance of individuals and organizations dedicated to strengthening the nation's undergraduate science and mathematics community. In addition to sponsoring workshops and publishing reports on issues of importance to undergraduate education, PKAL maintains a list of exemplary undergraduate courses and programs—what it terms "programs that work." Address: 1730 Rhode Island Ave., N.W., Suite 803, Washington, DC 20036. Telephone: (202) 232-1300. Internet: p00274@psilink.com. World Wide Web: http://www.augsburg.edu/pkal/index.html.

The **Association of American Colleges and Universities** focuses more broadly on improvements in undergraduate "liberal education," including science education. It publishes a quarterly journal, *Liberal Education*, and a quarterly newsletter, *Connections*, focused on the role of liberal learning in higher education. Address: 1818 R St., N.W., Washington, DC 20009. Telephone: (202) 387-3760. Internet: neal@aacu.nw.dc.us.

Periodicals that regularly publish articles on undergraduate biology education include *Bioscience* magazine, published by the American Institute of Biological Sciences (730 11th St., Washington, DC 20001-4521; 202-628-1500); the *Journal of College Science Teaching*, published by the National Science Teachers Association (1840 Wilson Blvd., Arlington, VA 22201; 703-312-9232); and *The American Biology Teacher*, published by the National Association of Biology Teachers (11250 Roger Bacon Dr., #19, Reston, VA 22090; 703-471-1134). In addition, the American Association for the Advancement of Science's journal *Science* and a number of disciplinary journals occasionally publish articles and special sections that deal with biology education.

The **Howard Hughes Medical Institute** has produced several publications featuring institutional profiles and highlights of the annual meetings of program directors from its undergraduate program. Address: Undergraduate Biological Sciences Education Program, Office of Grants and Special Programs, HHMI, 4000 Jones Bridge Road, Chevy Chase, MD 20815-6789. Telephone: (301) 215-8870. Fax: (301) 215-8888. Internet: grantvpr@hq.hhmi.org.

Interactive Video Network (IVN) connects 16 different institutions of higher education, including the five 2-year colleges that make up the state's Tribal College System. A single instructor can teach students scattered throughout the state, with the video screen displaying the person who has spoken most recently. "It's different than a canned lecture because of the interactivity," says professor Albert Fivizzani, who chairs the biology department at the university. Also, information can flow in any direction, not just from instructors to students. "Students and faculty at the tribal colleges can provide information to us as well," Fivizzani observes.

As technologies develop, the interconnectivity among systems is rapidly expanding—as exemplified by the explosive growth of the World Wide Web. Both students and faculty members have begun using electronic Web browsers regularly to surf the Internet and gather information from computers located anywhere from across campus to around the world.

At the Massachusetts Institute of Technology, computer communications have been undergoing a steady migration to the Web. Professors put syllabuses, problem sets, students' papers, tests, video clips, and other materials online, creating a vast network of interconnected information that anyone can access. Hundreds of student and faculty home pages contain photos, personal observations, and almost anything else that can be expressed in text and graphics. "What we're doing is creating communities of people who don't have to be in the same place," says Gregory Jackson, former director of academic computing at MIT. "Electronic communication breaks down all kinds of barriers of space and time."

The Web is not suited to all forms of academic computing, Jackson notes. It is good for moving information from one computer to another for display or storing, but it can be maddeningly slow. Locating desired information can be frustrating, and software generally must be downloaded rather than being used online—although this is beginning to change. Indeed, new enhancements are likely to expand the capabilities of the Web significantly. Exactly how the technology will evolve is anyone's guess; after all, the Web itself was developed just a few years ago.

The explosion of information technologies in academia raises a host of tantalizing questions. Will lectures eventually be replaced by electronically mediated presentations, with professors working one on one or in small groups with students? If electronic communications become the norm, what will be the effects on residential campuses? Will electronic communications augment the person-to-person connections that have been at the heart of effective teaching, or will they supplant those connections? These are difficult questions to answer, but they will be critical to the future of undergraduate education.

AN INFRASTRUCTURE FOR CHANGE

The rapid evolution of information technologies underscores the forces of change in undergraduate biology education. But focusing on innovations can be deceptive. Go into many biology classes today and you'll see a lecture style that has not changed in decades. Some scientists are masters of this style, engaging and inspiring their students, but many biology faculty members adopt the lecture format mainly because it is the most familiar to them. An increasing number of campuses have opened teaching centers to provide guidance on alternative methods, but faculty members pressed for time have trouble getting away from the laboratory. Faculty members also may lack a system to learn about teaching from their most successful peers or from outstanding biology faculty members elsewhere.

In her book *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't* (Tucson, Arizona: Research Corporation, 1992), Sheila Tobias draws a sharp distinction between innovation and change. Innovations often cluster around issues like course materials that do not upset long-established ways of teaching and learning. Yet without connections to the deeper issues of culture and expectations, innovations tend not to lead to lasting change because they do not alter what really matters. "What hinders students,"

The Wider Curriculum of Science

There's more to becoming a biologist than learning how to handle a micropipette and centrifuge. Students also must learn to work at a crowded lab bench, speak before a group of researchers, and observe the standards of the profession. Wesleyan University in Middletown, Connecticut, is one of a growing number of colleges and universities making special efforts to teach such skills. Even for students who do not go on in biology, this training can be a valuable asset:

- ***Writing and speaking clearly.*** "Expressing yourself as a scientist is very important," says David Beveridge, dean of natural sciences and mathematics at Wesleyan. "You're entering a new community and you need to learn the language." Students at Wesleyan make presentations on recent scientific papers at weekly journal club meetings, discuss posters on their research, and speak before larger gatherings. They also write frequently, with many courses requiring several term papers. "They have to learn how to do it," Beveridge says. "This isn't a spectator sport."
- ***Working in groups.*** Students at schools like Wesleyan know how to succeed individually, but they also must learn to work cooperatively in laboratories and other scientific settings. To encourage this, some Wesleyan professors have begun asking students to work in teams within the classroom. Most students in Al Fry's organic chemistry class, for instance, solve problem sets together, with their grades affected by the group's performance. Though some students object to this approach, the majority prefer it, according to Fry, who was inspired by Philip Uri Treisman's success with "cooperative learning" in mathematics classes at Berkeley and elsewhere.
- ***Acting ethically.*** In 1990, assistant professor of chemistry David Westmoreland began teaching a class that uses case studies to explore ethical issues in science, such as research integrity and the use of laboratory animals, and related social questions such as genetic testing. "There was a real dearth of training materials," he recalls. No longer. Westmoreland has built up an extensive resource base on these topics and recently received a grant to share materials with the many colleges and universities that now offer similar classes. "Some people might see this as wimpy, fluffy stuff," he says, "but if you're going to be a scientist, you need to be aware of these issues." Westmoreland's class, designed primarily for science majors, is regularly filled to capacity.

Professor Laura Grabel meets with biology students at Wesleyan University.

Without connections to the deeper issues of culture and expectations, innovations tend not to lead to lasting change because they do not alter what really matters.

Tobias writes, "are the pace, the conflicting purposes of the courses (to, variously, provide an introduction, or lay a foundation for a research career, or weed out the 'unfit'); attitudes of their professors and fellow students; unexplained assumptions and conventions; exam design and grading practices; class size; the exclusive presentation of new material by means of lecture; and the absence of community—a host of variables that are not specifically addressed by most reforms."

According to Tobias, lasting change rests on several key factors: a willingness to deal with complex and essentially political issues, a commitment to incremental improvements that reflect local conditions, and an infrastructure that can support the process of change.

One place where these three things have come together is the University of Wisconsin–Madison. The process began when several key faculty members decided that the balkanization of the life sciences at Wisconsin had gone too far. At the end of the 1980s, more than 700 faculty members in the life sciences were scattered throughout two colleges, three schools, and 37 departments, from agronomy and anthropology to wildlife ecology and zoology. Entering students quickly were funneled into one of the departments, from which they were unlikely to emerge. Responsibility for teaching introductory biology was so diffuse that one entry-level course consisted mainly of seniors who had been denied admittance in earlier years.

The departmental structure at the university was too entrenched to be reorganized without a struggle. So Paul Williams, a professor in the College of Agricultural Science, and a group of colleagues tried a different route. They convinced the administration to back a campus-wide Center for Biology Education that would provide a locus for faculty members interested in teaching. "Disciplines and departments are very isolating," says Williams, "but the commonalities in educating students are very strong."

One key decision Williams and the others made was to put the culture of research at the University of Wisconsin to work for education. They offered a series of competitively awarded minigrants to faculty members interested in teaching reforms. They also organized a single-credit course for freshmen called "Ways of Knowing Biology," where small groups of students spend successive weeks in the laboratories of different professors observing research firsthand. And they organized a series of lunchtime discussion groups, called "Biology Instruction Brownbags," where faculty members could get together to talk about what they were doing.

At the University of Wisconsin–Madison, Paul Williams has been leading an effort to coordinate biology education both across campus and nationwide.

"It doesn't work coming from the top," says Williams. "And it takes time. There are no grand conversions."

Out of such small steps has come lasting reform. A minigrant funded the writing of Jo Handelsman's book on active learning in biology. A computerized database for students describes the different courses and majors in the life sciences available at Wisconsin. New introductory courses are again serving lower-division students. The labs for the honors biology course have been completely redesigned to revolve around open-ended problems and investigative experiences. And similar ferment is under way in many other departments at Wisconsin, reflecting the administration's emphasis on teaching and a growing cross-talk among departments throughout the sciences and engineering. Because of the strength of the university's commitment to teaching, the National Science Foundation recently established the Institute for Science Education on campus, which will serve as an academic think tank for the agency's efforts in science education.

More recently, Williams has been leading a push to replicate the University of Wisconsin's success on a national level. For the past several years he has been overseeing the Coalition for Education in the Life Sciences, or CELS, which was established in 1991 by 30 scientific and teaching organizations to promote literacy in the life sciences. CELS has held four national meetings to define biological literacy, explore innovative teaching styles, and discuss institutional change.

A focus of CELS's work has been the involvement of professional societies in the process of change. Because of their central position in research communities, professional societies have unique opportunities to influence education. "If something happens within your own professional society, then it's a part of your culture," says Williams. "It's a way to bring together kindred souls in a way that doesn't threaten anyone."

Having an infrastructure for change is important at both the local and national levels, according to Williams. Within an institution the necessary infrastructure can support teaching improvements through release time, laboratory space, or new technologies. At the same time, a national infrastructure can produce models for reform and a sense that others are working on similar problems.

"An infrastructure is really just people," Williams says, "people with knowledge and wisdom. That's what makes the difference between success and failure."

Biology for Non-Majors

Some of the most interesting biology teaching is going on in classes for students who do not intend to major in biology. With coverage of prescribed subject material generally less of a concern than in majors' courses, faculty members are free to experiment with teaching styles and curricula that build on the specific interests of students and teachers. In the process, they are demonstrating approaches to teaching and learning that can improve *any* class.

At Yale University, biology professor Timothy Goldsmith teaches a biology course for non-majors that is one of the most popular science courses on campus. Entitled "The Biological Roots of Human Behavior," the course examines evolution, genetics, neurobiology, and behavior, concluding with a discussion of what makes humans unique. Attendance at discussion sections is required, and students write miniessays each week on issues where biology intersects with social concerns. "I don't consider the course I teach to be intellectually inferior," Goldsmith says. "It's *different.*"

Goldsmith chaired a National Research Council committee, funded by HHMI, that concluded in the 1990 report *Fulfilling the Promise: Biology Education in the Nation's Schools* that "something is profoundly wrong in how we inspire interest in science and convey knowledge about science to the next generation." He knows that many liberal arts majors have bad memories of science classes and are poorly prepared. But he believes they can be inspired to look at biology with fresh eyes—so long as their instructors meet them halfway.

Some of the most interesting perspectives on the course he teaches, according to Goldsmith, come from the graduate students who teach the discussion sections. "I've had teaching assistants say that this experience should be part of the undergraduate experience for biology majors as well," he says. "But we're so concerned with cramming details into the heads of majors that we frequently do not provide enough opportunity for reflection."

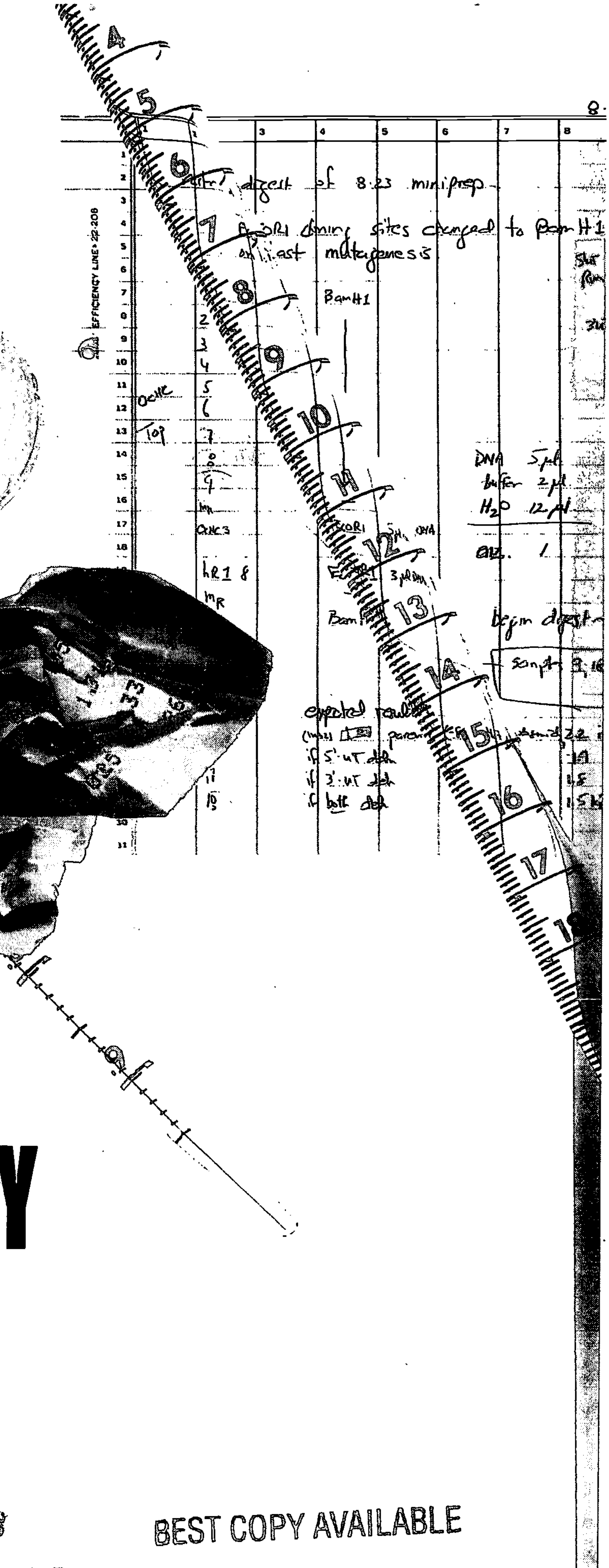
Many liberal arts majors have bad memories of science classes and are poorly prepared.

Goldsmith spends considerable time working with the teaching assistants to acclimate them to a new style of teaching. "We try to get the students to talk with each other about what they've learned, and that requires spending time with the TAs, getting them to talk with each other and with me." The resulting dialogues among students and instructors open up areas of discussion that many biology majors never experience. "I've had TAs tell me that there are pieces of this course they've never studied before. That says something about the narrowness and focus of undergraduate science education."

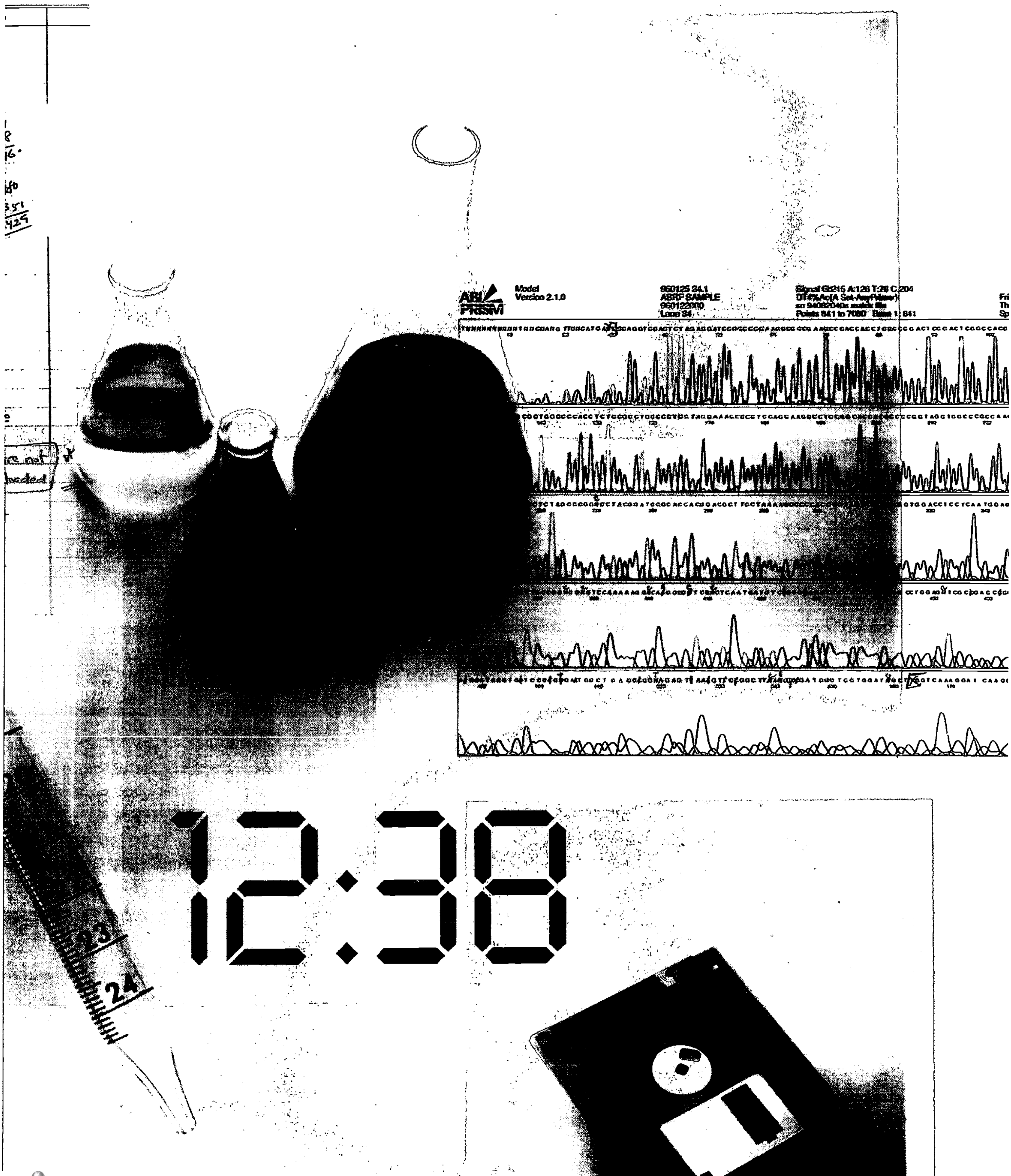
CHAPTER 3

Biology students approach teaching laboratories with mixed emotions. For some, laboratory courses are windows on the world of science, allowing them to gain experience with the techniques, concepts, and emotions that go with real research. For others, laboratories are exercises in preordination, a tedious derivation of answers that are already known to questions that do not seem important.

Often, the best laboratory experience is one in which students pursue their own research under faculty guidance. In fact, given the success of undergraduate research, more and more faculty members have begun asking: Why not make teaching laboratories more like research projects? Instead of just showing students what it is like to do science, why not confront them with real problems and ask them to come up with their own solutions?



THE LABORATORY EXPERIENCE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Students presented with such a challenge must develop traits such as curiosity, creativity, and perseverance—the very attributes essential in science. They also hone skills, such as problem solving and using computers to manipulate equipment, that may get short shrift elsewhere in the curriculum. Most important, they are more engaged than in "cookbook" laboratories, enhancing not only their knowledge of biology but also their confidence in themselves.

University of Chicago students Hugh Kim, Joy Hatzidakis, and John Jakob talk in the new Biological Sciences Learning Center, which was designed to blur the distinctions between research and education.

More and more faculty members have begun asking: Why not make teaching laboratories more like research projects?

VARIATIONS ON A THEME

Open-ended laboratories can take many different forms, according to professor Marshall Sundberg, a botanist at Louisiana State University in Baton Rouge. An instructor might give students information and ask them to solve specific problems. A series of "What happens if...?" questions may lead students to discover basic concepts. Or students may simply be given some preparation and materials and then be asked to design and carry out their own independent explorations.

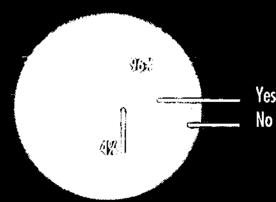
The basic ideas behind what are often called investigative laboratories have been around for years. In 1971, as part of the work of the Commission on Undergraduate Education in the Biological Sciences, professor John Thornton laid out the principles behind such laboratory courses in his book *The Laboratory: A Place to Investigate*. "The general notion that you should engage students in investigations as a vehicle to teaching them science, that wasn't anything new 25 years ago," says Thornton, who recently retired from Oklahoma State University's biology department. "What was new then, and is still new now, is the idea that you can use this approach with all students."

Though the concepts underlying investigative laboratories are straightforward, they have generated a profusion of approaches in practice:

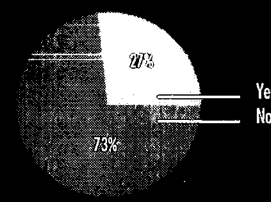
- At Bates College in Lewiston, Maine—as part of a thorough revamping of the undergraduate biology curriculum—the biology department has adopted an approach in its introductory courses that resembles the "principal investigator" system of research. Small groups of students design and conduct experiments. Each group designates one person to draft a paper presenting the results, with the other group members reviewing and revising the paper. In this way all biology students write about 10 scientific papers by the end of their sophomore year.
- At the University of Chicago—where every undergraduate takes a year of biology, including a laboratory—the new $40 million Biological Sciences Learning Center was designed to blur the distinction between research and education. Built as a "one-room schoolhouse" for biology, the building combines classrooms, teaching laboratories, and research laboratories, all arrayed around a light-filled atrium where undergraduates, medical students, and graduate students sprawl on sofas and gather around tables to eat and talk. "The faculty here believe that biology is an experimental science, so that you can't teach biology to either majors or non-majors without laboratories," says professor José Quintans, master of the biological sciences collegiate division.
- At the University of Washington, the purchase of videomicroscopy equipment and a set of computers for data acquisition has catalyzed a new approach to teaching laboratories. "A private activity—looking down a microscope—has become a social one of watching a video screen," says biology professor John Palka. "The group situation automatically generates student involvement and

An Investigation of Biology Laboratories

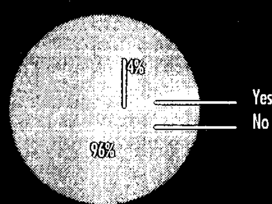
In 1991 Marshall Sundberg of Louisiana State University and Joseph Armstrong of Illinois State University in Normal surveyed the biology departments of 76 top research universities and state universities to determine the status of undergraduate biology laboratories. The results point toward a wide range of different practices, but they also demonstrate the continuing reality for many students of large underfunded laboratory courses taught predominantly by teaching assistants.



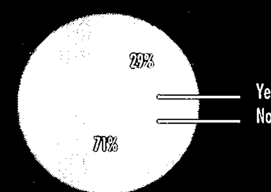
Is laboratory instruction a part of introductory biology at your institution?



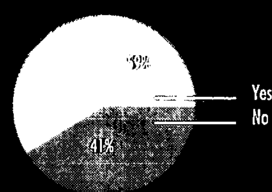
Do you employ career instructors to teach laboratories?



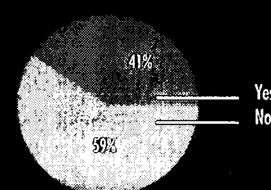
Do you use investigative laboratories in all your biology classes?



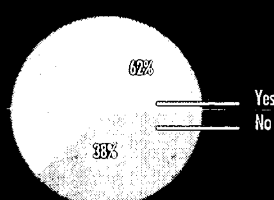
Do undergraduates assist in laboratory instruction?



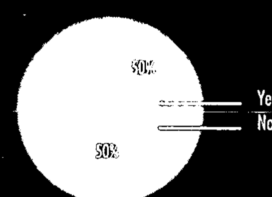
Do your introductory biology classes enroll more than 500 students?



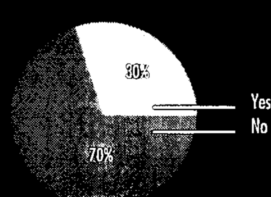
Is your student-to-instructor ratio greater than 20 to 1?



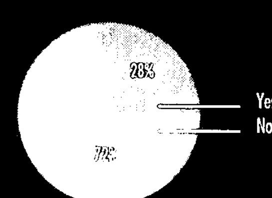
Does your institution offer separate biology courses for majors and non-majors?



Is your supplies budget greater than $10 per student per semester?



Do at least some tenure-track faculty members teach in biology laboratories?



Do you charge biology students a laboratory fee?


pencil crayons

The majority of the elementary education students who take Biology 295 at the University of Nebraska–Lincoln claim to "hate science" before the course begins. But the course, which uses hands-on projects like the one shown here to help future teachers overcome their fear of science and engage young students in investigative learning, has a dramatic impact on student attitudes. By the end of the course, 95 percent of the students claim to enjoy science.

discussion at a much deeper level than 'Is this what I'm supposed to be seeing?'" An unexpected bonus, Palka reports, has been the interest of students in using computers to do experiments quickly and easily. "A student can do biology in minutes rather than spend the whole first day trying to control the oscilloscope beam."

• Beloit College professor John Jungck and his colleagues at other institutions have been leading the effort to build the BioQUEST Library, a collection of computer-based tools, simulations, and textual materials that support collaborative, open-ended investigations in biology. Developed at campuses around the country, each module in the library simulates or explains a different biological system, allowing students to analyze massive amounts of data and visualize the relationships among variables. For example, one of the ten core modules, SequenceIt!, simulates the processes used in protein sequencing. Each module must involve students actively in learning, go through an intensive peer review process, and be proven effective in the classroom. "My greatest joy as a teacher," Jungck says, "is to get an evaluation that says something like, 'I became a good problem solver in this class.'"

MAKING THE TRANSITION

The routes that institutions take in making the transition from traditional to investigative laboratories are as varied as the outcomes. Harvey Mudd College in Claremont, California—traditionally a physical sciences and engineering powerhouse—had a chance to make the transition when it upgraded its biology department and began to offer a biology major in the late 1980s. The introductory biology laboratory that existed at that school then had not changed in years. "It was pretty much a cookbook approach," says biology professor Nancy Hamlett. "We measured bacterial growth rates. We did enzyme kinetics. But when you talked to students later, they didn't seem to internalize anything. Nothing seemed to sink in."

"People are amazed when they find out how few labs we do. But as soon as we tried it, we were convinced that students were learning a lot more biology."

The department held a retreat to talk about what a new introductory laboratory should accomplish. "We really wanted students to understand the experimental approach to biology, how biologists investigate meaningful things," recalls Hamlett. "We wanted them to understand what a control was, and how to design an experiment. They weren't getting any of that before."

Faculty members hoped to retain a broad focus on biology but to do so more effectively. They therefore dropped the number of laboratory exercises from 12 to 4—one each on ecology, biochemistry, molecular genetics, and neurobiology. "People are amazed when they find out how few labs we do," Hamlett says. "But as soon as we tried it, we were convinced that students were learning a lot more biology. It's much more interesting when you're thinking about what to do as opposed to doing something out of a cookbook."

In the new laboratory the students spend a week learning about the subject of each exercise and choosing a scientific question to investigate. They spend another week gathering data and then two weeks analyzing data, refining their experiments, and writing up the results. After working with a writing consultant to revise the first draft, each student turns in a paper that closely resembles a journal article.

As in the classroom, trading quantity for quality raises the question of whether a laboratory is covering enough material. But faculty members who teach the course insist that greater understanding serves students better than exhaustive coverage. "Maybe our students won't have experienced all of the techniques that people elsewhere do," says associate professor Catherine McFadden, who teaches an ecology laboratory in which students gather data on organisms at Laguna Beach. "But they'll be more flexible and will understand more about how science is done." Certainly the record of Harvey Mudd's biology majors reflects the department's confidence: in the past few years, about half the biology majors have gone to biology graduate school.

The students are as enthusiastic as the faculty members. "The other labs I've taken here were like the labs I had in high school," says junior Phil Cheung. "That was before I came

RESOURCES

The **Council on Undergraduate Research** (CUR) seeks to provide students and faculty members at mostly undergraduate colleges and universities with increased research opportunities. It issues directories that document the role of research in undergraduate departments, publishes the journal *CUR Quarterly*, hosts biennial national conferences, administers a consulting service for science departments, supports selected students on summer research projects at their home institutions, and maintains a national database on undergraduate research. In addition, CUR's biology division publishes a biennial directory of undergraduate research in biology at primarily undergraduate institutions. Address: University of North Carolina at Asheville, One University Heights, Asheville, NC 28804-3299. Telephone: (704) 251-6006. Internet: stevens@unca.edu. World Wide Web: http://www.unca.edu/cur.

The **Association for Biology Laboratory Education** (ABLE), founded in 1979, promotes the exchange of information among university and college educators who are actively concerned with teaching biology in a laboratory setting. An annual conference features hands-on workshops where individuals from across the United States and Canada share successful laboratory exercises. The presentations are published in *Tested Studies for Laboratory Teaching*, with past volumes available for purchase. Membership information: Nancy Rosenbaum, Department of Biology, Yale University, P.O. Box 208104, New Haven, CT 06520-8104. Telephone: (203) 432-3864. Internet: nancy.rosenbaum@yale.edu. World Wide Web: http://www.zoo.utoronto.ca/~able.

The American Biology Teacher, published by the **National Association of Biology Teachers**, regularly publishes descriptions of laboratory exercises. Designed primarily for high school biology classes, many of the exercises can be adapted for college use. Address: 11250 Roger Bacon Dr., #19, Reston, VA 22090. Telephone: (703) 471-1134.

The **BioQUEST Library** contains computer-based tools, simulations, and textual materials from across the country that encourage students to work collaboratively in exploring biology. Each module examines a different biological system. Subscription information: The ePress Project, Academic Software Development Group, Computer Science Center, Building 224, University of Maryland, College Park, MD 20742. Telephone: (301) 405-7600. Internet: asdg@umdd.umd.edu. World Wide Web: http://terrapin.umd.edu/BioQUEST_Library.html.

The **Beta Beta Beta Biological Honor Society** recognizes superior academic achievement among undergraduates and promotes the study of biology. It publishes a quarterly journal, *BIOS*, and sponsors regional and national meetings where students can present the results of their research. Address: P.O. Box 670, Madison, NJ 07940-0670. Telephone: 201-377-8407. Internet: tribeta@drew.edu.

The **Howard Hughes Medical Institute** publishes a series of colorfully illustrated scientific reports for a general audience. Recent titles include *The Race Against Lethal Microbes; Seeing, Hearing, and Smelling the World;* and *Blood: Bearer of Life and Death*. Address: Office of Communications, HHMI, 4000 Jones Bridge Road, Chevy Chase, MD 20815-6789. Telephone: (301) 215-8855. Fax: (301) 215-8863. Internet: commpub@hq.hhmi.org.

to biology lab. Here you're actually working the same way that scientists work. In other labs you turn in your laboratory notebook and say good-bye."

COMMON ELEMENTS

Investigative laboratories take many different approaches but share a few key elements. They shift the emphasis from the professor as teacher to the student as learner. "If we're about anything," says Jungck, "it's about putting students first." Students memorize facts and master concepts but also make informed judgments, develop effective work habits, and use such attributes of scientific thinking as objectivity, thoroughness, and precision. In the process they get valuable training for future careers in not just biology but many different professions.

Instructors also assume a different role in investigative laboratories. Instead of being the primary source of information for the class, a faculty member or teaching assistant becomes a mentor, helping students work through problems. "Faculty members have to be very comfortable and confident in their own understanding," says Sundberg of LSU. "They also have to be willing to give up the traditional authority that an instructor has in class. That's the biggest barrier to investigative labs, more so than money or time. It's probably the largest reason why the technique hasn't taken off in the past 20 years."

Learning how to run investigative laboratories often requires special training. At LSU, for example, graduate students take a for-credit course to prepare them to teach in investigative laboratories. "We try to make instructors relate to their graduate experience and bring that attitude to the undergraduate level," says Sundberg.

Faculty members also need time to develop new laboratories and learn new teaching styles. Open-ended laboratories are not necessarily more demanding of faculty hours than traditional laboratories, according to instructors who have made the switch. But they take time to develop and often must be revised to reflect new developments.

Perspectives on Undergraduate Research

HEATHER FITZGERALD

Heather Fitzgerald, a senior at the University of Colorado at Boulder, got involved in undergraduate research the traditional way: she responded to an ad for a dishwasher in the laboratory of Lorraine Pillus, an assistant professor in the Department of Molecular, Cellular, and Developmental Biology. It didn't take long before Fitzgerald was assisting a postdoc with a project and, with a research stipend from the university, undertaking her own experiments.

For her senior research project she focused on *SUN1*, a gene involved in the transcriptional control of genetic information in yeast. Studying how genomic DNA can be activated or silenced helped to activate her own interest in biology. "I thought that's what I wanted to do with my life, but I wasn't sure," says Fitzgerald, who plans to attend graduate school in biology. "I had a view of science as sitting in a corner with a microscope all day."

Instead, she found the laboratory to be extremely social. "I didn't expect it to be so interactive," she says. "The postdocs, the grad students, and Lorraine all take so much time to explain everything. You don't get that in your regular classes."

MICHAEL SKINNER

For University of Delaware senior Michael Skinner, research was the culminating experience of a rich undergraduate life. Yet the experience simply whetted his appetite for something more.

For a senior project Skinner worked to develop a nuclear magnetic resonance (NMR) probe that can measure metabolic processes in riboflavin-deficient chicken embryos.

"No one person knew how to do this," he says, "so I had to talk to the people on campus who know about NMR, and to some researchers in Canada, and to the people in the electronics shop who know how to solder the pieces together." Named one of the top 20 undergraduates in the country by *USA Today*, Skinner is "the model of a person who can do everything," according to his research supervisor, biochemistry professor Harold White.

That description also applies outside the laboratory. Originally a biochemistry major, Skinner switched to the liberal arts to pursue broader interests in theater, art, philosophy, and English. He has acted in a number of plays and helped design the sets for others. He has tutored young biochemistry students at the university. And he is the founder and co-president of IMPACT, a residential community service organization that works with students and disadvantaged members of the local community.

Skinner has not yet decided whether to go on in research. "There are a lot of things that interest me," he says. "So I'm trying to think about a career that combines a lot of different things."

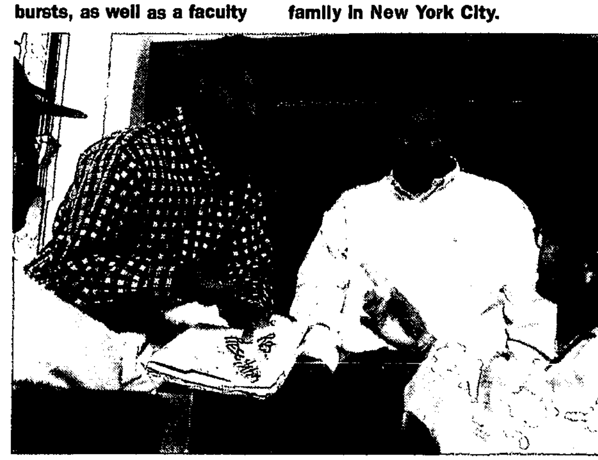
JORGE TORRES AND GABRIEL ORTIZ

For undergraduates, independent research projects can be much more than just another way to earn credits. They can lead to new ways of thinking and working and to students taking a view of science that cuts across disciplines.

At Yale University a group of undergraduates organized a series of meetings where they compare their experiences with classmates majoring in other disciplines. The first session featured student talks on membrane binding proteins, planetary physics, and gamma-ray bursts, as well as a faculty lecture on the molecular origins of life.

"I've learned from studying molecular biophysics and biochemistry how multidisciplinary science is," says Jorge Torres, who helped plan the symposia. "I thought students should learn science in a multidisciplinary fashion."

The Undergraduate Science Symposia also help students polish their presentation skills and provide an informal support network, especially for minority students who participate. "When you see someone from your ethnic origin presenting, you say, 'Oh, I can do that,'" says fellow organizer Gabriel Ortiz, who presented a talk on using metal affinity chromatography to purify the binding domain of botulinum toxin, a neurotoxin used to treat certain neuromuscular disorders. "It helps to motivate you," he says. Like Torres, Ortiz came to Yale from a Puerto Rican family in New York City.



Gabriel Ortiz (left) and Jorge Torres lead undergraduate science symposium at Yale University.

Broadening the Horizons of Pre-Meds

Some undergraduates view biology class as a ticket to punch on their way to medical school. But pre-meds can be encouraged to take a broader view of the discipline. Often, they are simply unaware of the many other ways in which biology can be put to work.

Johns Hopkins University has developed one remedy: an annual seminar series that introduces undergraduates to other career options. Shin Lin, associate dean for research and graduate studies and chair of the biophysics department, hosts the popular sessions like a talk show. Recent guests included AIDS researcher Flossie Wong-Staal, ethnobotanist Mark Plotkin, geneticist Victor McKusick, and Merck structural biologist Paula Fitzgerald.

Lin interviews the guests about both their scientific activities and career paths. The guests speak for about 40 minutes about their fields and research interests, and then the audience asks questions. The series is so popular, often attracting 200 or more students, that Lin had to move it to a campus auditorium. "I'm the Jay Leno of science," he jokes.

THE ELECTRONIC LABORATORY

Teaching laboratories are changing as faculty members recognize the benefits to students. But laboratories are also being forced to change because of pressure from an unexpected quarter: the rapid development of information technologies.

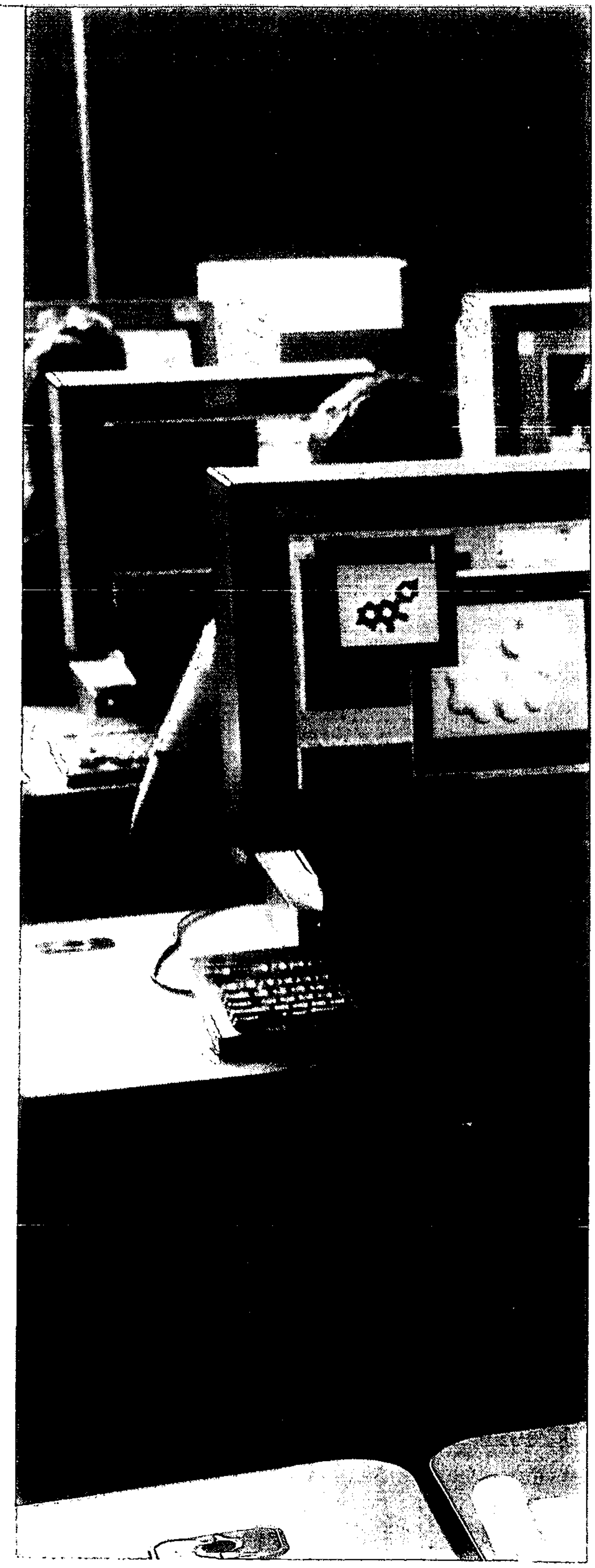
Students are using computers to simulate dissections, manipulate molecular structures, model the functioning of nerves, and recreate evolutionary lineages. In the process they are raising fundamental questions about the nature of learning and the distinctions between real and simulated experiences.

"Computer technologies are the first thing since the printing press to make a real difference in the way we teach and learn," says Frank Vellaccio, provost of the College of the Holy Cross in Worcester, Massachusetts. Computers connected to campus networks or the Internet enable students to tap into vast quantities of data and to visualize and manipulate information in a host of new ways.

Carnegie Mellon University in Pittsburgh, with its traditional emphasis on advanced technologies, has been a pioneer in putting computers to work in biology education. In its Division of Molecular Sciences, which encompasses the chemistry and biology departments, computers are ubiquitous—from the first teaching laboratories to the research projects that students pursue with faculty members.

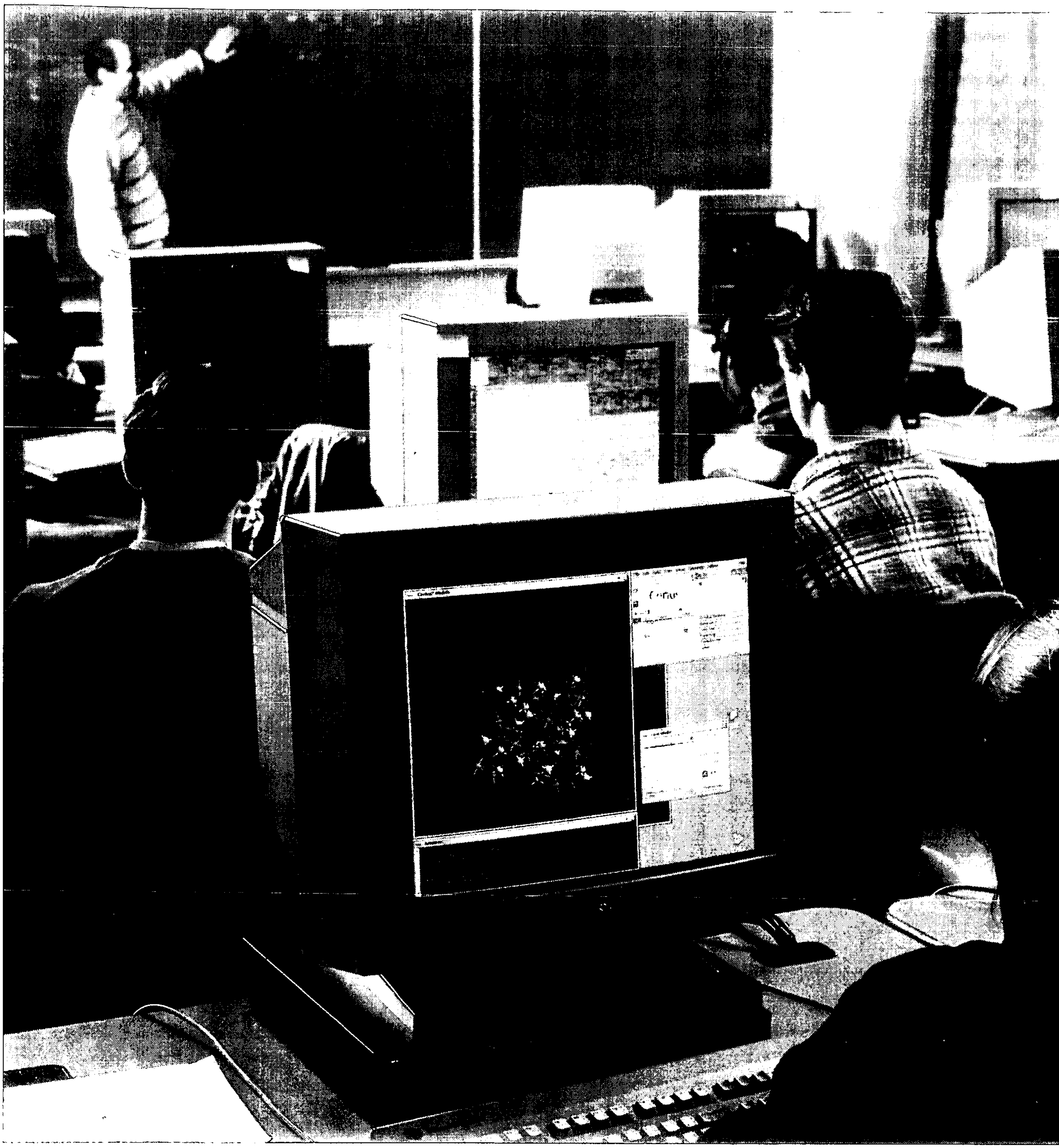
In some classes, computers have *become* the laboratories. Chemistry assistant professor David Yaron and biology associate professor Robert Murphy have developed laboratories in computational chemistry and computational biology that take place entirely at a keyboard. Using both a conventional computer laboratory and one outfitted with 24 networked graphics workstations, students perform investigations with the computer as their experimental apparatus. "The students are actually running experiments at their workstations," says Yaron. "We can give our students real problems to work on, using exactly the same program that people use to do drug design, for example."

In the computational laboratory for biology, students work on a broad array of problems in



a similarly open-ended fashion. They compare protein sequences, model neural behavior, and enhance images from microscopes. "The interactivity of the computer strengthens the laboratory experience for students," says Murphy, who compares this virtual experience with conventional wet labs using real materials.

"In a wet lab, if you wanted to change the



conditions, you would have to go back and start the experiment again," Murphy says. "In our lab the changes you make are immediately reflected in what you're doing."

The rapidly increasing power of computers to simulate biological systems inevitably raises the question of whether computers will eventually replace wet labs. But those who have worked with both kinds of laboratories say this question misses the point. Each approach offers certain benefits; the challenge is to blend them together successfully. At Carnegie Mellon, for example, students who take the computer laboratories also take a full slate of wet labs.

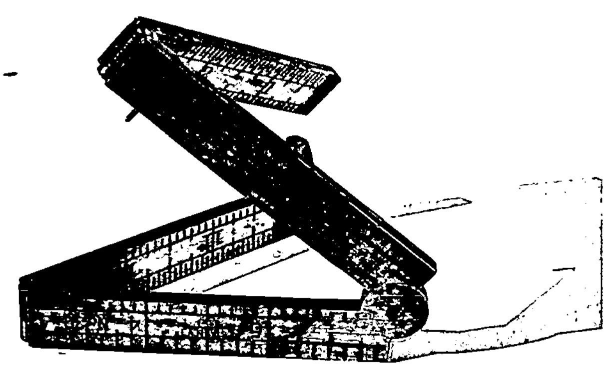
"Using computers to run a multitude

At Carnegie Mellon University a new computer laboratory enables students to carry out experiments at 24 networked graphics workstations.

The Challenge of Assessment

Do innovative teaching techniques and investigative laboratories really lead to improvements in student performance? Faculty members who have adopted them think so. But that's hard to prove without objective measures of student outcomes.

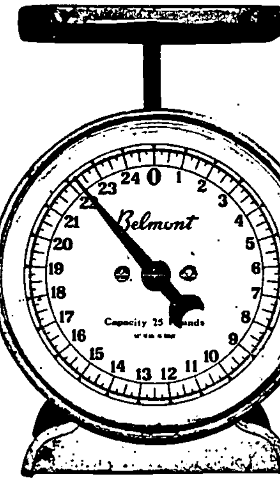
The first question to be answered is: What should be measured? Is simple exposure to biology classes and laboratories a useful indicator of success? Should the breadth or depth of student knowledge be evaluated? What is the most important: mastery of a body of knowledge, a student's conceptual understanding, or the attitudes a course inculcates?



The University of California–Los Angeles is among the many institutions grappling with these issues. Over the past few years, several science departments at UCLA have teamed up with the psychology department to assess new science teaching approaches more rigorously. "When we evaluate our own programs, we invariably succeed," says chemistry professor Orville Chapman, who, as associate dean for educational innovation, has been leading an effort to incorporate educational technologies into campus science departments and evaluate their effects. "When cognitive scientists evaluate our programs, the initial evaluation is usually rather bad.... I urge anyone seriously interested in producing really good learning programs to have independent evaluation by cognitive scientists."

One of the assessments at UCLA compared two sections of a laboratory. The students in the first section were taught with the aid of computers; those in the second section were taught solely by human instructors. The most significant finding, according to Chapman, was the difference in attitudes between the two groups of students. Almost all of the students in the first section were much more enthusiastic about the course and about studying science. Among women, the difference was even more pronounced. In fact, all of the women who took the computer-based course thought they learned more and rated it more highly than other laboratory courses they had taken. "It's the first time I've ever seen UCLA students agree on anything," says Chapman.

Yet when the students taking the two different sections took the same tests for the course, the results showed no difference in learning. "What that says to me," Chapman concludes, "is that we haven't learned how to measure what matters in education." The tests used in the course largely measured learned facts, whereas the computer laboratories focused more on developing skills such as problem solving. "It's very hard to probe understanding in a systematic way that you can document," says Chapman. "So even though the students thought they had gained in understanding, the course did not assess for that."



Steven Heidemann, a professor of physiology at Michigan State University in East Lansing, also has been asking whether new forms of teaching can produce demonstrable effects on learning. A team of faculty and staff members at Michigan State developed a multimedia computer program called BioSci Explorer, which includes 13 full-color animations that help students visualize three-dimensional structures and processes. Students were enthusiastic about the new program and used it heavily in campus computer laboratories. Yet they performed no better on multiple-choice tests than did earlier students who had not used the program. "Students say they like it better," says Heidemann. "They say it helps them understand the material better. But when we measured how they did on exams, we didn't find any difference."

At Lousiana State University, Marshall Sundberg and his colleagues have had greater success measuring the results of new teaching styles by focusing on concepts rather than factual knowledge. In the process of shifting from traditional to investigative laboratories, Sundberg and his colleagues found that the new laboratories have produced a marked increase in students' understanding of basic biological concepts. Yet in this case student attitudes about the new course were mixed. "It depends on when you hit them with the questionnaire," says Sundberg. "Early in the semester the course is really frustrating for a lot of students. The tools they've developed for studying don't work real well. But in the second half of the semester we see student satisfaction coming back up, and by the end of the course a lot of students love it."

UCLA's Chapman calls assessment "the crabgrass in the academic lawn," and much more work must be done before cognitive research can offer detailed guidance to college faculty. But Chapman, Sundberg, and others point out that college faculty need not reinvent the wheel. Much valuable work on assessment is being done at the pre-college level. For example, the National Science Education Standards developed by the National Research Council call for assessments that "probe for students' understanding, reasoning, and use of that knowledge—the skills that are developed through inquiry."

A reexamination of assessments often has an unexpected dividend, report faculty members who have spent time on the issue. Thinking about assessments forces people to consider the goals of undergraduate biology education. Assessments focus on what faculty members think is important to teach, which is why changes in assessment often drive more far-reaching changes in education. "If we don't change the means of assessment, we had better forget about reform," says Chapman.

of *Drosophila* crosses is a great use for this tool, but it should not substitute for students having the opportunity to handle, manipulate, and lose live fruit flies," says Jay Labov, professor of biology at Colby College in Waterville, Maine. Though financial pressures might push some institutions to substitute computer laboratories for wet labs, according to Labov, "using both approaches is best."

"Computers aren't replacements for wet labs, they're enhancements," agrees Susan Henry, dean of the College of Science at Carnegie Mellon. "Computers and laboratories are going to become two parts of the same entity. They feed each other, and what's exciting is to bring the two together."

The real issue, according to Henry and other administrators with responsibility for biology laboratories, is one of resources. Many biology laboratories are already limping along with inadequate space, aging equipment, and little money for student supplies. New computers are a further drain on resources. Computer hardware and software, moreover, are changing so rapidly that obsolescence is always looming without continual upgrades.

Many institutions rely on students to bring their own computers to college, but not all students have computers or know how to use them. "Although some of our students are rich enough to drive Range Rovers, many more cannot afford $2,000 to buy a computer," says Martha Crunkleton, dean of the faculty at Bates College. "We need to make sure that we address equity issues when considering the use of technology."

Equally difficult is the issue of how faculty members can be convinced not only to use new technologies but to take advantage of their interactive potential. As described in the next chapter, many faculty members already feel stretched juggling their teaching, research, and other responsibilities, much less finding time to master new technologies and teaching approaches. What's more, they may see little professional reward in doing so. "How do you decide what to invest time and talent in?" asks Susan Henry of Carnegie Mellon. "I'm not worried about people wanting to apply technology. I'm worried about the university's ability to support it."

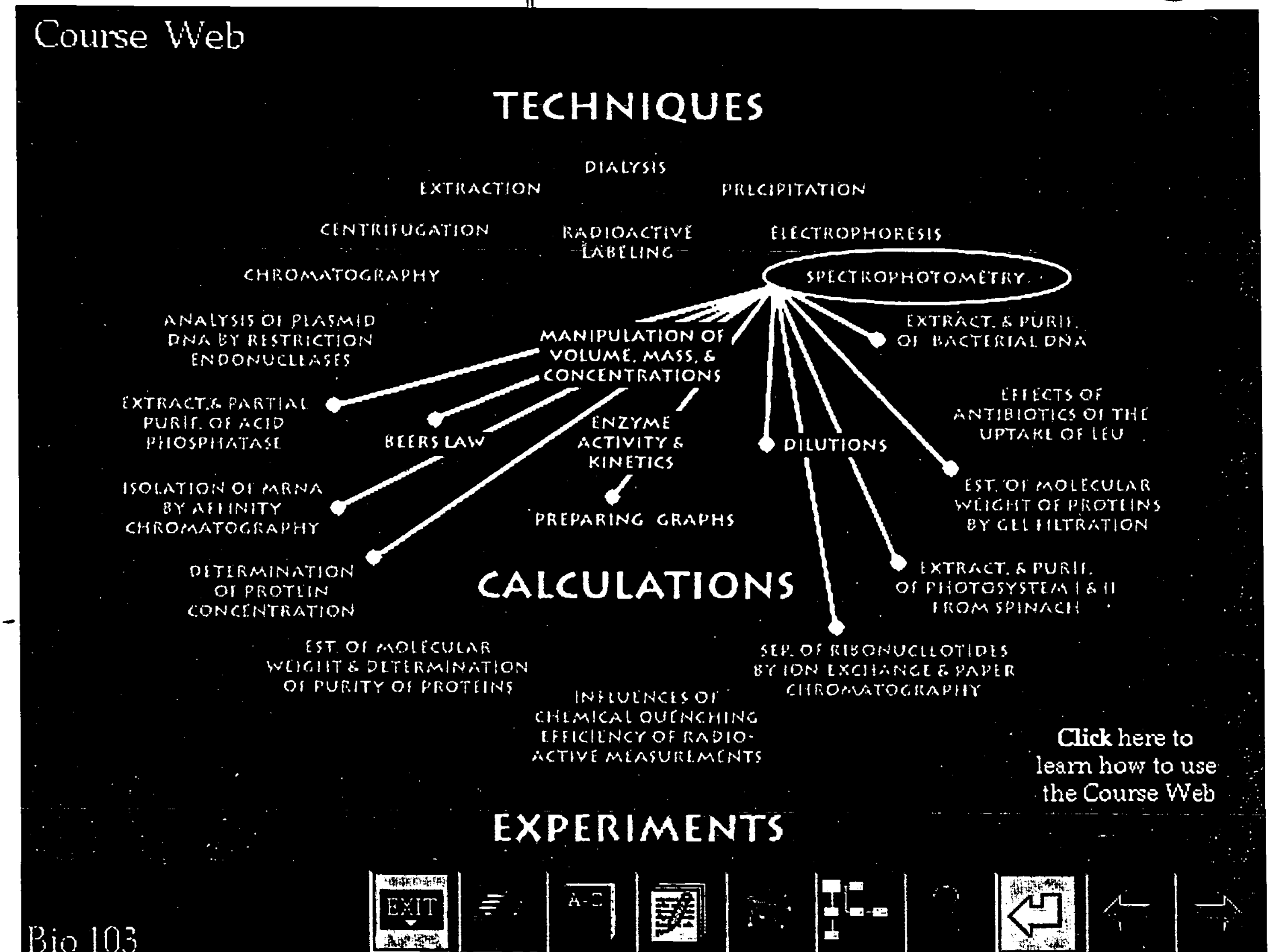
Some colleges have made the development of educational materials, including software, a more formal part of the professional rewards system. Many have been granting faculty members leave time to develop computerized educational products. Some have built sparkling new computer facilities to entice faculty members into the electronic age. Wofford College in Spartanburg, South Carolina, for example, used a foundation grant to construct a new building containing 11 classrooms outfitted with advanced video and computer projection technologies. So far, 20 percent of the college's faculty members have produced multimedia presentations, and many more have used the new technologies to teach their classes. "We want to empower the faculty and at the same time give them greater flexibility," says Wofford vice president B. G. Stephens. "Because if the faculty don't have flexibility, I don't care how much power you give them, they won't use it. I believe technology can and should be used to encourage and enhance individual teaching styles, not to put faculty in some predetermined mode."

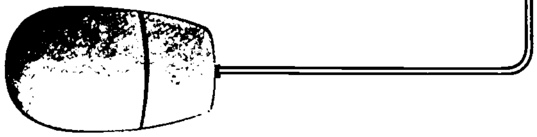
"Computers and laboratories are going to become two parts of the same entity. . . . What's exciting is to bring the two together."

To many faculty members the scope and speed of change can seem overwhelming. Yet as the price of computers and network connections continues to fall and software grows ever more sophisticated, change becomes inevitable. If the goal of a lesson is to help students understand how a new drug might fit into the binding site of a protein, it's hard to resist new programs that enable students to model the process for themselves.

Indeed, students who grew up with computer games and manage their own home pages are among the most forceful advocates for the new technology. "Whenever I see a professor marking up an overhead with a bunch of colored pens," says David Bellows, a University of Arizona graduate who is now a graduate student in biology at Johns Hopkins University, "I say to myself, 'What a dinosaur.'"

Education in an Electronic Age





The Interactive Lab Manual

45

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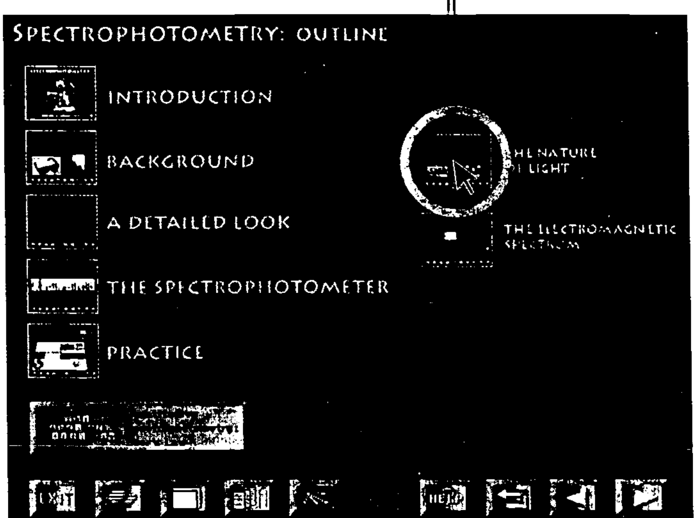
When students at the University of California–San Diego (UCSD) take the laboratory course "Biochemical Techniques," they confront a stark juxtaposition of the old and the new. In one room is a conventional wet lab filled with glassware, exhaust hoods, and emergency showers. In a nearby room is an array of computers running a sophisticated program called the Interactive Lab Manual (ILM). The information being conveyed in the two rooms is similar. But the combination of the real and the virtual produces a powerful learning experience that illustrates how new computer technologies are enhancing undergraduate biology education nationwide.

The course web (left) is the point of entry for the Interactive Lab Manual. Students can click on calculation modules (center of diagram) to learn quantitative principles. Technique modules (top half of oval) demonstrate procedures such as spectrophotometry and chromatography. Experiment modules (bottom half of oval) simulate wet lab exercises. Clicking on any part of the course web reveals the connections between modules (yellow lines).

The ILM gives students an opportunity to learn about the terms, principles, and techniques of experiments through electronic simulations. "They can gain confidence with a piece of equipment before they ever touch it," says Gabriele Wienhausen, who has headed up the development of the program with fellow UCSD faculty member Barbara Sawrey. "It's tremendously empowering for students."



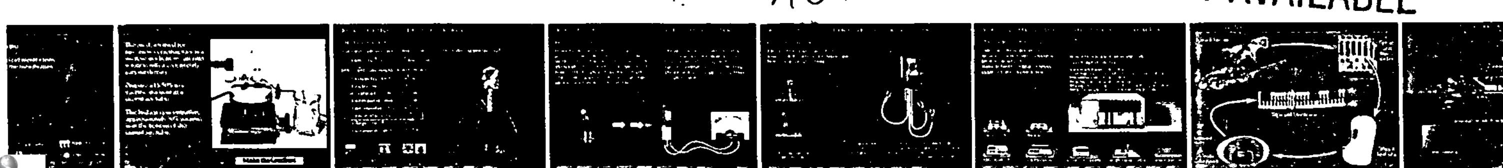
Double clicking on any of the modules brings up an outline (above). The outline suggests one possible way to move through the module, but a student can go directly to areas of special need or interest. For example, a student might choose to review the nature of light by clicking on the indicated icon.

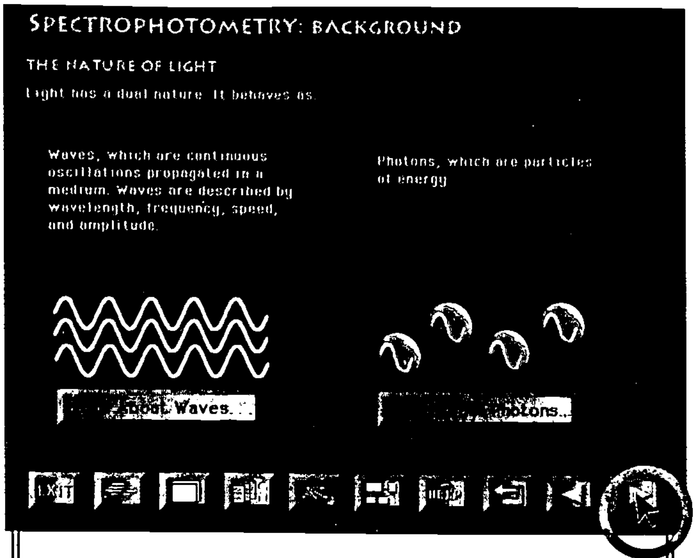
The program is broken into modules that correspond with the experiments that students undertake in the wet lab. It includes animations, videos, links to instructors, and "virtual instruments" with which students can practice before they tackle the real thing.

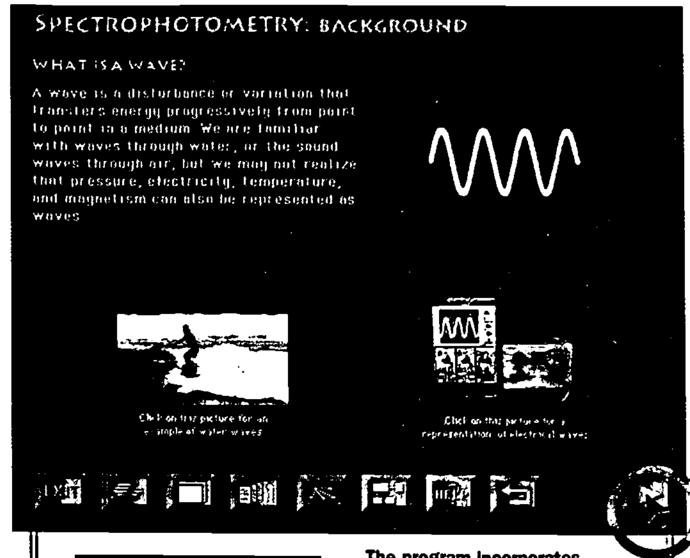
Rather than progressing in a linear fashion like a book or a videotape, the course is structured like a web, with students creating their own paths. Students can skip over familiar material and spend more time with topics of special interest to them. Links to the University of California's on-line card catalog and to abstracts of biological and chemical research articles reinforce the idea that knowledge is constantly changing and expanding.

One of the great advantages for instructors is being able to study the routes students take through the program. "We know that people construct knowledge in their own ways," says Wienhausen. "This way we can tap into their thought processes and learn how they learn." At the same time, the program's developers are using data on how students progress through the modules as well as student comments to improve the program's design.

The program's developers have sought to make it as attractive and interactive as possible. Almost every screen includes a special twist to keep students engaged. "People our age have grown up with video games and music videos," says Scott Kelley, the recent UCSD graduate who has been leading the programming team for the project. "It has to look good or you're not going to use it."

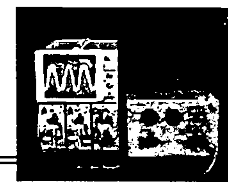




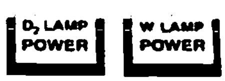


The program gives students the option of learning more about how light can behave either as a wave or as a particle. Clicking on the "next page" arrow, in this case, leads to a discussion about the general characteristics of waves.

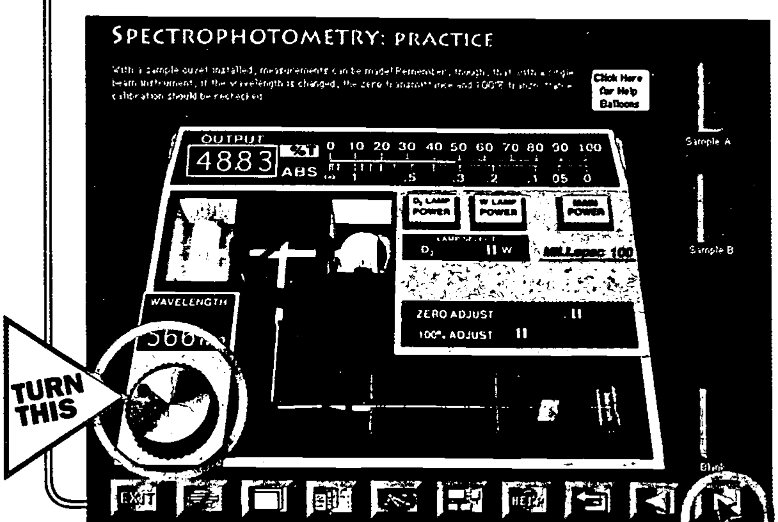
The program incorporates videos and audio text to supplement images and the printed text. Clicking on the surfer in this screen sets him into motion as he rides the wave toward shore.

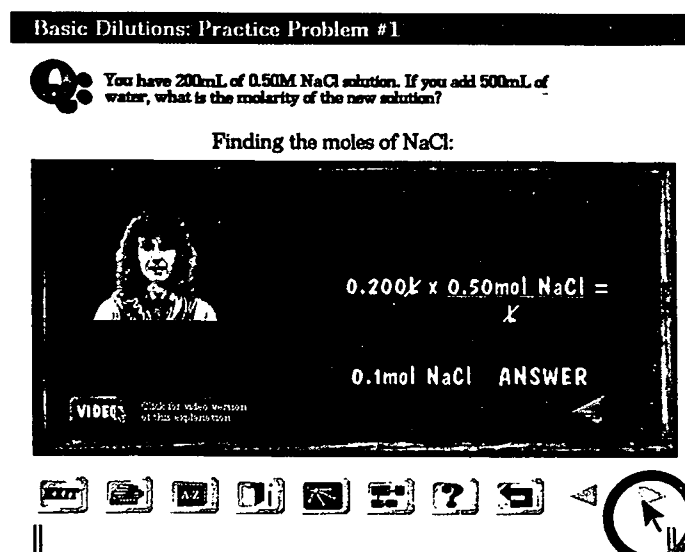


Part of the spectrophotometry module is a "virtual spectrophotometer." Turning the wavelength knob with the mouse causes the components within the spectrophotometer to operate just as they would in the actual device, but with the top removed so their functions can be seen. Students also can calibrate the instrument and observe the impact that poor calibration has on the absorbance measurement. Learning this helps them avoid similar problems with real spectrophotometers.



Students following the spectrophotometry module may want to review how to make dilutions. By clicking on the course web button and then on the dilutions module, they can move to sample problems that provide written, spoken, and visual explanations of each step. Clicking on the photograph of program developer Gabriele Wienhausen provides a video explanation of the technique.





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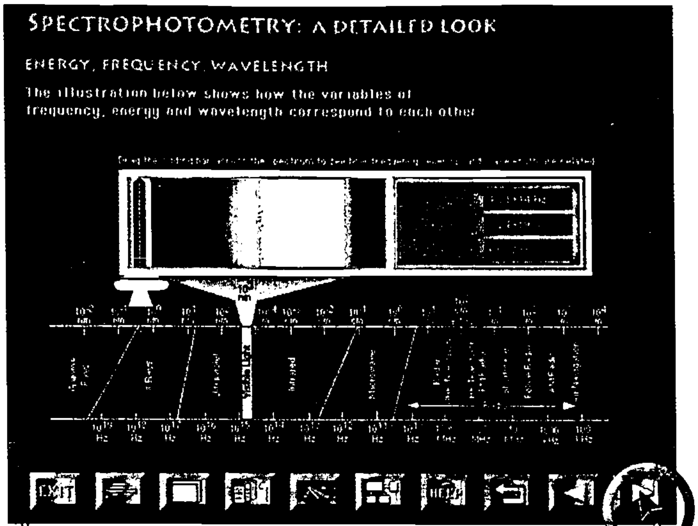
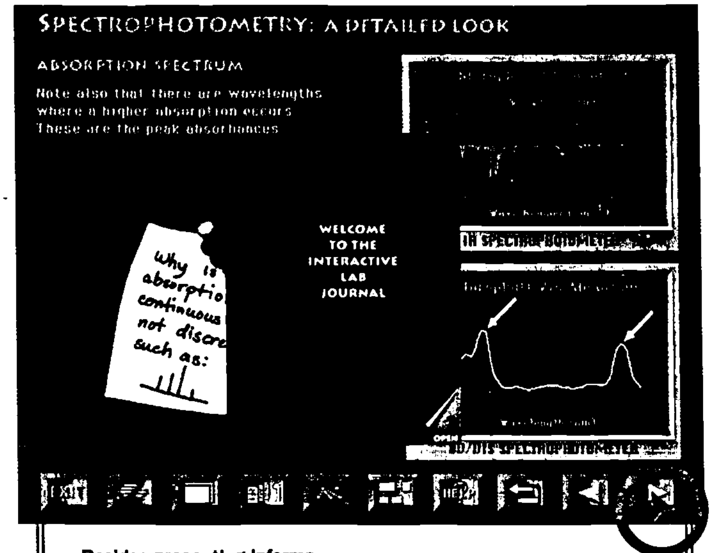
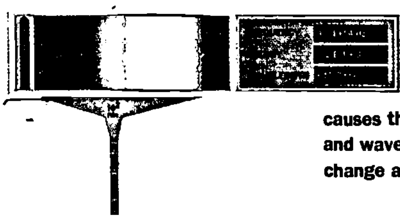
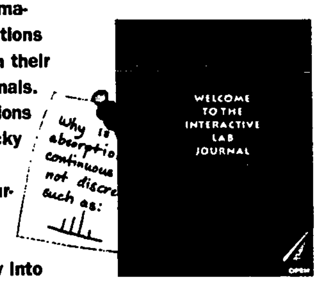




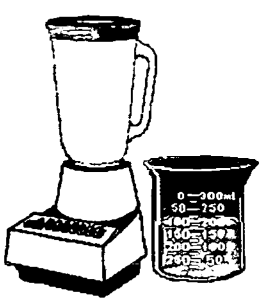
As a student moves deeper into the subject of waves, an interactive display relates wavelengths to the size of physical objects. Moving the slit on the spectrum causes the frequency, energy, and wavelength quantities to change accordingly.



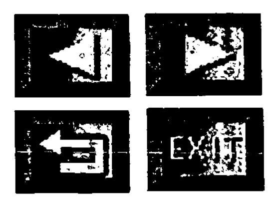
Besides presenting information, the ILM poses questions for students to answer in their own Interactive Lab Journals. "Food for thought" questions written on electronic sticky notes invite students to write answers in their journals. Students also can cut and paste material from any module directly into their journals, producing their own custom-designed notes.

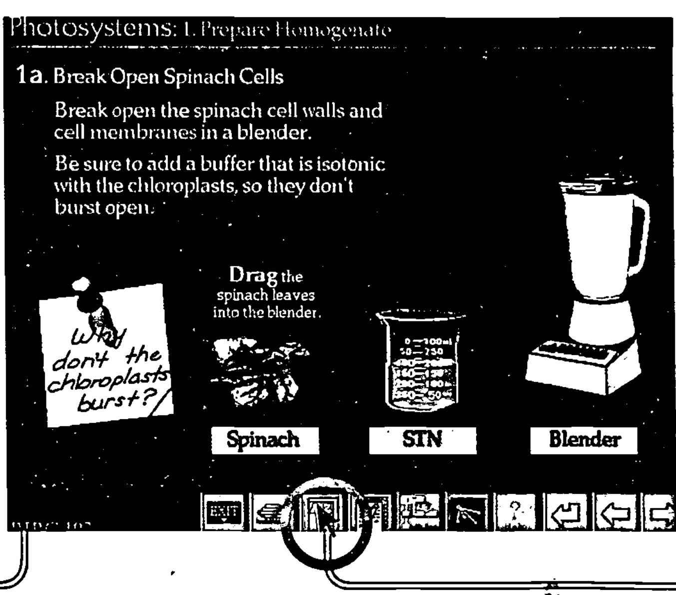


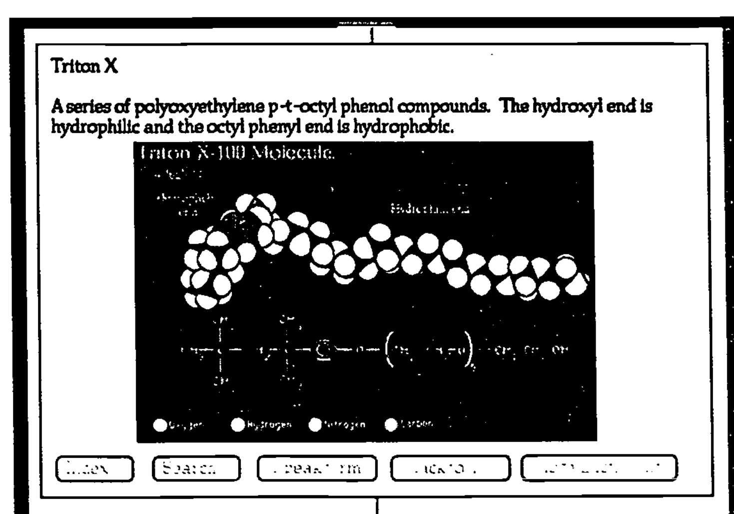
Once they understand the basics of spectrophotometry and dilutions, students can undertake a complete electronic experiment such as extracting and purifying photosystems from spinach. Moving the spinach leaves to the blender sets in motion an electronic blade that homogenizes the solution.

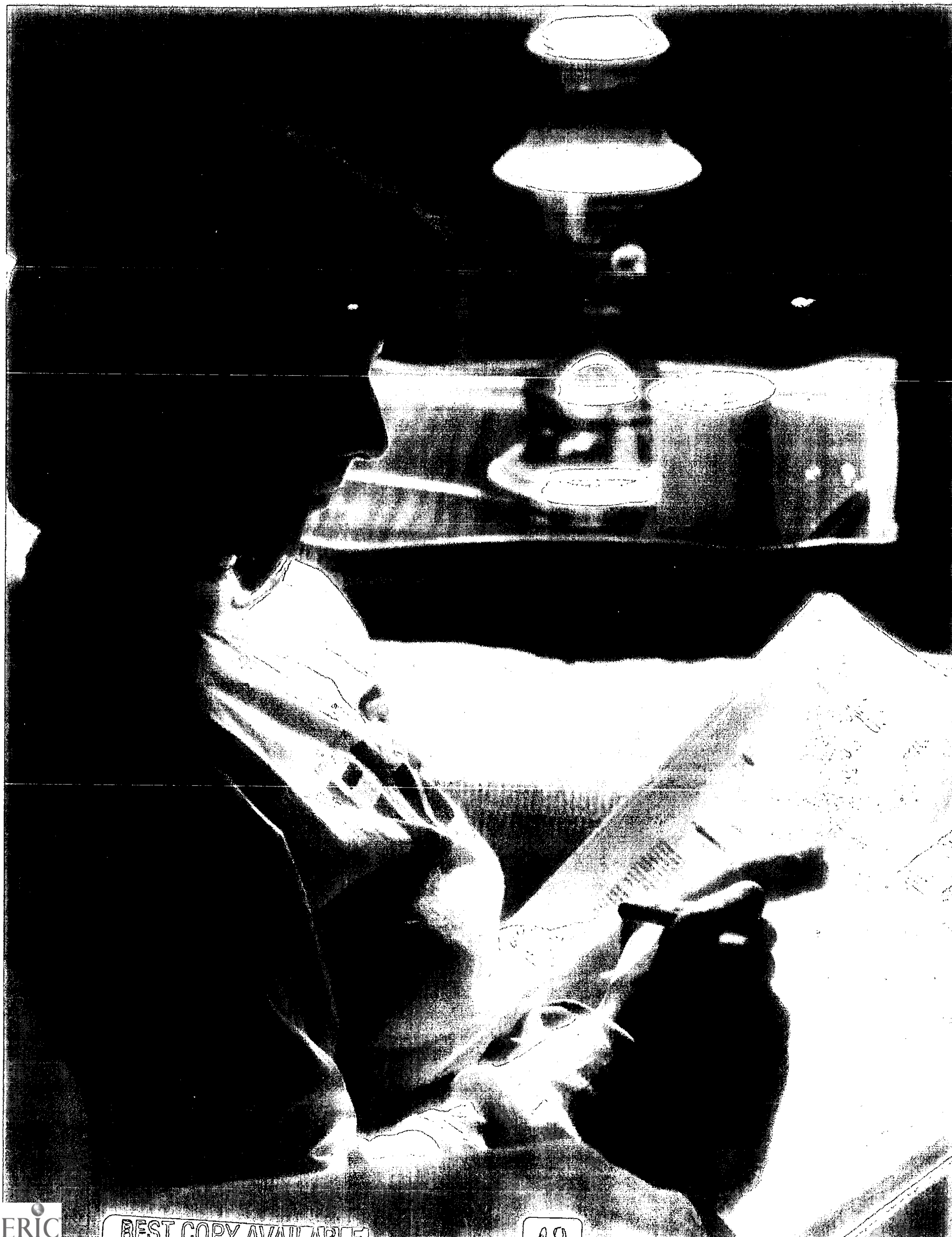


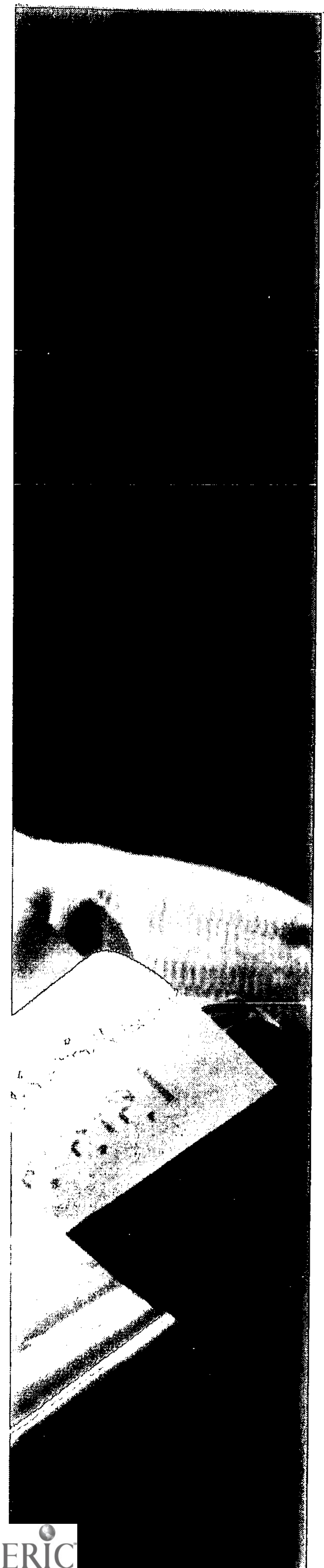
At any time, students can open the on-line dictionary through their toolbar and get a definition of scientific words and phrases used in the Interactive Lab Manual. Other buttons on the toolbar lead to the outline for the module, to an extensive help section, or to the University of California's on-line catalog.











FACULTY IN THE CROSSFIRE

CHAPTER 4

The clock is ticking, and Janine Maddock is on her way to Room 1003. Maddock could be—and probably should be—elsewhere tonight. But she has agreed to spend two hours talking to the undergraduate biology club at the University of Michigan–Ann Arbor about her career as a scientist.

"I really shouldn't have agreed to do this. This does nothing for my career. I'm too busy this year. I can't take on anything else. I don't have time for one more thing," Maddock says as she strides briskly down the hall toward Room 1003.

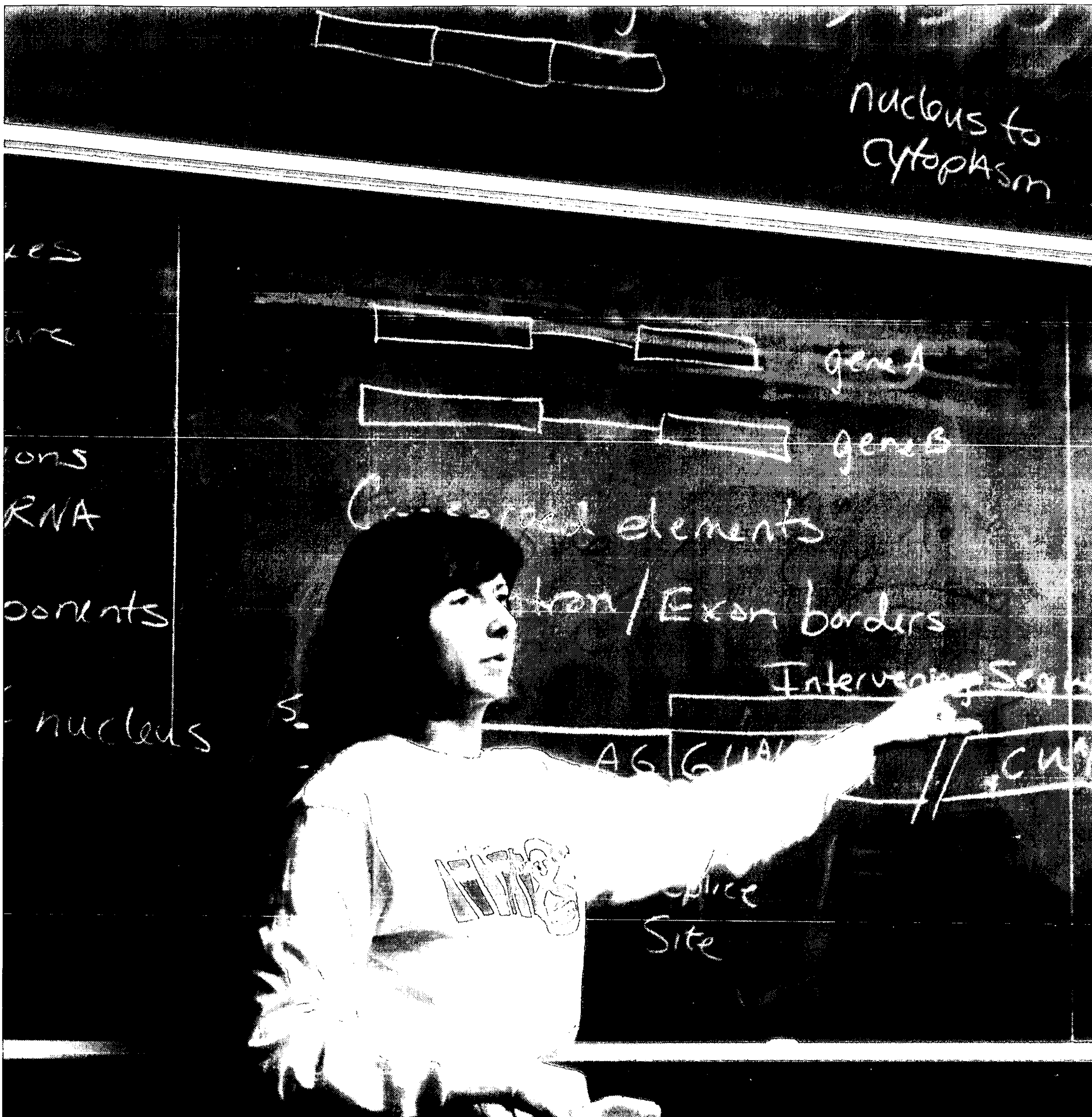
Maddock is devoted to teaching. Yet this is the month when the young biologist has two deadlines to apply for grants—including a prestigious R01 grant from the National Institutes of Health—that will keep her genetics laboratory productive for several years. Without grant money, Maddock believes that everything she wants in her professional life is in jeopardy. So why, in the face of that pressure, is she taking time to talk with a group of undergraduates?

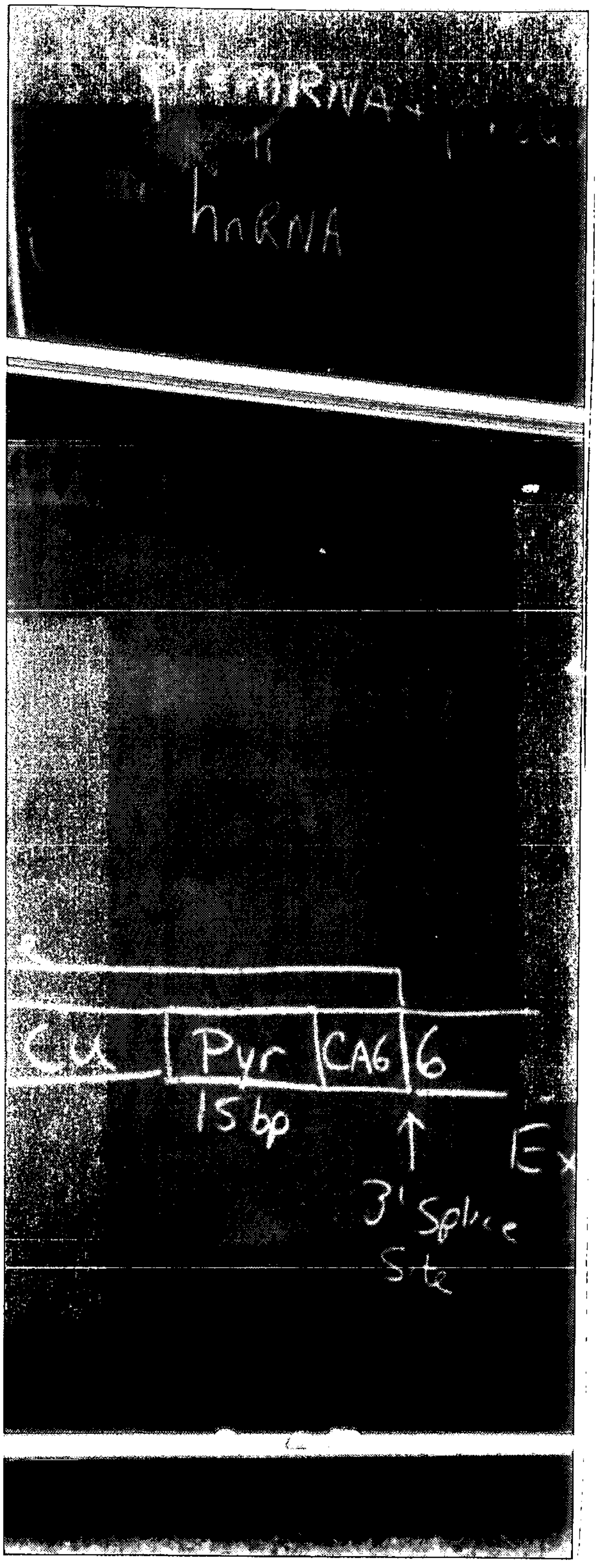
"They're at the stage where they don't know what they want to do," says Maddock. "I want to signal to them that learning is fun.... This is worth it if it will get these students on the right path to learning science. This is part of my job, too."

Janine Maddock, like biology faculty members across the country, is on the front lines of undergraduate education. The approaches to biology education described in this book will not take hold unless she and others adopt and extend them.

Her professional life, which is described in this chapter, exemplifies the dilemma faced by faculty members everywhere who care deeply about undergraduate education but are pulled in a dozen other directions every day. Her life is a whirlwind of teaching, grant writing, research, family, and other responsibilities. She is committed to her students and to teaching well. But to be in a position to teach, she must get the grant support she needs to do research.

Maddock's situation as a new assistant professor at a research-intensive university is especially intense. Indeed, the difficult period described here will ease with Maddock receiving a major grant that provides a career boost and breathing room to pursue her research. But all biology faculty are familiar with the kinds of pressures described in this chapter, and the starkness of those pressures provides a


cytoplasm
gene A
gene B
RNA
elements
Exon borders
Site



She is committed to her students and to teaching well.

useful reality check for anyone seeking to improve the quality of undergraduate science education. Who will make needed changes? Will they be rewarded for doing so? And, most important, where will they find the time?

From the minute Janine Maddock stepped into her laboratory on the Michigan campus in January 1995, the tenure clock started ticking. She came to Michigan after completing a postdoctoral fellowship with Lucille Shapiro, an eminent developmental biologist at the Stanford University School of Medicine. "I'm constantly reminded that I don't have tenure," Maddock says. "I have been told so many times not to do something because of tenure. I hate having to think about it. I hate having to worry about whether they're going to like me or not because I've put my nose in the wrong place when my heart's in the right place."

In her first two years the University of Michigan will devote $200,000 in resources to get her genetics laboratory off the ground. After that she has to convince the federal government and private agencies to give her about $100,000 a year to keep the laboratory afloat. "My job is to be in this lab, to get research dollars, and to get this laboratory up and running," she says. "It builds up my reputation. It builds up the department. It builds up the university. That's my job."

She is working on two of the hottest topics in biomedical research—cell fate and the mechanisms of cell cycle control. Using the bacterium *Caulobacter crescentus* as a model, Maddock seeks to explain how cells differentiate to assume different jobs and locations in a developing organism. "How do cells tell the difference between the end and the side of the bacterium, and why are the two ends different?" she asks. *Caulobacter* is a "beautifully asymmetric organism" for studying how proteins are asymmetrically directed to the two poles and elsewhere in this process.

Maddock's research interests extend beyond developmental biology to include the cell cycle, the sequence of biochemical events by which a cell grows and divides into two daughter cells. Biologists have long been interested in

For Maddock, teaching extends from the lecture hall through office hours to informal meetings with students.

Research is inseparable from teaching during weekly laboratory meetings (top) or while carrying out experiments (bottom).

cell division but only recently have begun to discern its complexity and relevance to cancer and other diseases.

Maddock focuses on a specific checkpoint in the *Caulobacter* cell cycle, the moment when the cell completes its long "G1" gap and begins to replicate its DNA. She has uncovered one of the actors in this drama—a protein with an eerie resemblance to the *ras* protein, which is known to play a role in certain cancers. "What's exciting is that this protein appears to be conserved in all organisms, from yeast and worms to humans," Maddock says. "No one knows yet what the hell it does, but it seems to have something to do with cell cycle control."

She is working on two of the hottest topics in biomedical research—cell fate and the mechanisms of cell cycle control.

While still a postdoctoral fellow, Maddock published papers in *Science* and other leading publications. "The beautiful thing about *Caulobacter* is that the field's not terribly crowded," she notes. Nonetheless, she is hardly alone in studying questions that may shed light on some of biology's most perplexing mysteries. Her laboratory competes with others around the world that are much larger and better known. She seems to relish the challenge almost as much as the science itself.

Maddock's life entails much more than grant writing and research. She is constantly juggling teaching, writing, and service commitments to the biology department and to students. According to biology professor Richard Hume, who served on the search committee that chose Maddock from among 150 applicants, "Research is the number one priority, but at this university you can't ignore teaching while you get your research in place.... What was absolutely clear from Janine's seminar and interview was that she was going to be a top-notch teacher as well as a top-notch scientist."

A significant portion of Maddock's life is devoted to working with undergraduates. Three times a week she lectures about 120 students in molecular biology. One night a week she teaches a graduate course in cell biology.

Maddock's classroom style is traditional, eschewing electronic presentations or participatory classroom projects in favor of lectures. She regularly supplements the course material with recent research findings. A talk on

This is a place where you can enjoy yourself —even if you're working 16 hours or more a day.

chromosome structure, for instance, concludes with new findings about how telomeres at the ends of chromosomes may be involved in cancer. An explanation of nucleotides leads to a consideration of how AZT and other drugs interact with the AIDS virus.

Maddock emphasizes that she is teaching upper-level courses for students who are already interested in biology, and she devotes her energies to developing high-quality lectures that help students focus on what science can do. "The kind of information I have to get across is very detailed. It's very high level, and there's a lot of it."

At the end of the semester, the students fill out evaluations and give Maddock high marks for her teaching. "You are very enthusiastic and easy to learn from," one student writes. "Don't become a cynical tenured professor," writes another. "We like you how you are now!"

Teaching at Michigan goes well beyond the lecture hall. "When she's not lecturing in the classroom, it's not like she isn't teaching," says Hume. Assistant professors in biology must counsel undergraduates at least two hours a week. They are encouraged to incorporate undergraduates into their labs—at Michigan, 40 percent of the undergraduate biology majors will work in a laboratory before graduation. "I absolutely love having undergraduates in my lab," Maddock says. "It's a lot of work, but it's fun. I don't feel like this is an extension of my teaching so much as it is a different *kind* of teaching."

Balanced against these academic demands are Maddock's family obligations. She is divorced and shares custody of her two children—Jaren, 5, and Jennette, 10. An undergraduate lives with her, earning free room and board in exchange for several evenings a week of child care.

"My rule is that my kids come first," Maddock says. "That doesn't mean that I'm always there when I want to be or when I need to be. It means that if I ever thought I was compromising their happiness or well-being, I'd leave this job." So parent meetings at school, Girl Scout meetings, play auditions, field trips, sick days, and time to color and read and make cookies often take her away from her laboratory and her students.

Tenure . . . grant writing . . . publishing . . . research . . . teaching . . . children—any one of them is taxing, but Maddock is trying to balance them all.

"I'd like it to be easier on her," says her mother, Nancy Parmelee, during a brief visit to Ann Arbor. "I have other kids. They don't have to work so hard as she does."

Maddock does not deny that her balancing act frequently becomes shaky. "As an assistant professor, you're on the ladder, but you're just holding on to the bottom rung. You could fall off at any moment."

Does it really feel that precarious?

Maddock pauses before she responds. "Yes. Yes, in a lot of respects, it does."

As one walks along the fourth floor hallway of the natural sciences building, Janine Maddock's laboratory is hard to miss. An orange and blue basketball hoop and backboard stands just outside her laboratory door. The door is variously decorated with tabloid clippings and cartoons. Inside, a portable CD player blasts whatever music appeals to whoever is working that day. At Christmas, hundreds of exotic lights in the shape of everything from hot chili peppers to flamingoes adorn the lab.

All of this is a calculated effort on Maddock's part to demonstrate that science is creative and fun, not stodgy and boring. This is a place where you can enjoy yourself—even if you're working 16 hours or more a day.

Today, Maddock's work day begins at 5:30 a.m. After making coffee she settles in to work on the two grant applications that are due in two weeks. For two precious hours, she hunches over her computer terminal writing. Then she spends 30 minutes going over academic files for the undergraduates she will counsel that morning. During the weeks preceding a grant deadline, she will devote almost no time to her research.

At 8 a.m. the first student arrives. Maddock is supposed to spend only 20 minutes per student but ends up devoting almost an hour to each. One pre-med student gets very specific advice about preparing for the medical school admissions test and how to enhance her transcript to become a better candidate for medical school. Next, Maddock sketches out an academic plan for a sophomore who wants to major in microbiology.

"A lot more goes into the job of teaching than most people ever know," she says. "We counsel. We mentor. We advise. It's a lot more than just delivering a lecture."

After the counseling session, she has an hour's break. But it's not enough time to work on one of the grant applications or conduct an experiment. "The problem with being an assistant professor is that my life is filled with one-hour chunks of time," she says. "You can't do science in one-hour chunks."

Although work in the laboratory has slowed to a crawl during grant-writing season, Maddock has not abandoned her weekly Thursday lab meetings. At 11 a.m. the three undergraduates, three graduate students, and one full-time technician gather to discuss their work. On the white board, graduate student Sally Green has scrawled a note: Arginine is positively charged!!!

"Our Janine" laughs at the pun and erases the board. She gobbles a cookie that one of the students has made in the shape of *Caulobacter*. But her casualness is deceptive. As soon as undergraduate Lucia Cardenas begins presenting her first paper to the group, Maddock is all business. At one point she asks, "How did they know that?"

"They guessed," says Lucia confidently.

"They guessed? They hypothesized?" Maddock responds.

Lucia, taking the hint, adjusts her statement. "They postulated that..."

Maddock shines in this small intimate atmosphere, helping students think critically about what they've read. As usual, the lab meeting runs late, ending at 12:50 instead of noon.

At 1 p.m. Maddock is finally back in her corner office overlooking the Michigan campus. It's an ideal office for catching the flavor of the campus. But as she settles in for an afternoon of work, she is oblivious to the warm sunshine and shouts from strolling students that stream through the windows.

Though she should be writing her grant application, Maddock instead begins drafting study questions for her graduate course. It should only take 20 minutes, she says. Ten

Training for Teaching

Like Janine Maddock, many assistant professors face tremendous pressures to become productive researchers. Yet studies show that their commitment to teaching remains strong.

"Assistant professors don't sacrifice their teaching," says University of Michigan–Ann Arbor psychology professor Wilbert McKeachie, who works with Michigan's Center for Research on Learning and Teaching. "You'd think they would because they have so much to do. But studies have shown that they spend an inordinate amount of time on teaching."

One thing that would help faculty members meet their teaching obligations, McKeachie believes, is better training for the job. Faculty members themselves often admit that they feel ill prepared as teachers and unfamiliar with alternative approaches. "I do think the old lecture style could be changed, but I don't really know of other meaningful ways to teach 150 students by myself, " says Lynn King, an assistant professor who teaches a large genetics course at the University of Miami in Coral Gables, Florida."

Mark Peifer, an assistant professor of biology at the University of North Carolina at Chapel Hill, says, "I spent 10 years learning how to be a scientist, and I got pretty good at it. But no one trains you in any of the things that you do once you get here.... They think that if you can give a good seminar, you can teach anyone."

Many colleges and universities have set up centers that offer training to graduate students and faculty. But in the midst of other obligations, many professors never have time to take advantage of such opportunities. The basic issue is one of incentives, says Steve Haynesworth, an assistant professor of biology at Case Western Reserve University in Cleveland, who earned a master's degree in education before embarking on his biology Ph.D. "Historically, if I was a below-average lecturer and mentor but wrote really good grants, I'd get tenure in a moment," he says. "But if I got all kinds of teaching honors but brought in no grants, I'd be let go. Within the past few years, however, there are signs that the relative emphasis placed on teaching and research by the university administration is becoming more balanced."

McKeachie agrees that worry about tenure overshadows junior faculty members' willingness to devote much time to improving their teaching. "It's not that they don't want to do well," he says. "It's that they're under the gun for promotion. They're not going to take any chances."

Maddock and her children walk near their home.

minutes into the questions, undergraduate Jennifer Skidmore volunteers to help locate journal citations for the grant. As soon as Maddock turns back to the graduate class questions, lab tech David Chavez interrupts with a question about some renovations going on in the lab. At 1:36 an undergraduate from her lecture class drops in to chat about an upcoming exam. When he complains about the course textbook, Maddock invites him in to sit down and talk in more detail as she takes notes on his concerns. Twenty minutes later she assures him that he'll do fine on the upcoming test. "Just don't stay up and study until 4 a.m. the day of the test. Remember, the test isn't until 7 p.m. You can study during the day," she reminds him.

At 2 p.m. he leaves, and a few minutes later the study questions for the graduate students are done. At last Maddock turns to her grants.

But for the next three hours the interruptions are almost constant. Maddock could change that by closing her office door, but she won't. Having an open door invites interruptions, but she prefers that to the message she thinks she sends by keeping it shut.

At exactly 5:12 p.m. she bolts out of her chair and heads out the door to get her son, Jaren, from his kindergarten school and then Jenny from her elementary school. By 6 p.m. everyone is home. Maddock fixes dinner, checks Jenny's homework, reads to Jaren, and tucks them into bed by 9 p.m.

Maddock leaves the children with her live-in student and is back on campus by 10 p.m. to meet with another faculty member for advice on her grant application. They talk until midnight, and then Maddock heads to her office. With a drawer full of "grant-writing cookies," freshly made coffee, and no distractions, she is finally able to concentrate. For six hours she writes more or less steadily. Then at 6 a.m. she heads home to shower and wake the kids for school.

By 8 a.m. she is back in the laboratory to start all over again.

Maddock's grant applications are due in about two weeks, and it is becoming clear that she is not going to be able to finish them on time. One day she is interrupted by a call from Jenny's school. Her daughter is sick and needs to be picked up. The next morning Jenny is too sick to return to school, so both of them stay home—Jenny in bed and Maddock at her computer, once again working on her grant applications.

Over the weekend another assistant professor volunteers to take care of both children so that Maddock can work. But after a weekend spent mostly at the computer, the realization sets in: she can't possibly finish both applications. The NIH grant has another deadline a few months later. She decides to put that off and finish the American Cancer Society junior faculty award application.

That Monday she meets with the members of her laboratory to tell them that she won't be applying for the NIH grant for several more months. She spells out the implications for them: Here's how much this grant is worth. This is when the money would arrive. This is how long the money would last. If I don't have the money to get to this point, here's what will happen.

The university urges faculty members like Maddock to develop close relationships with students, but allowing students so much access to one's personal life has a price. Michigan's associate provost Susan Lipschutz calls it a "two-edged sword."

"In science, faculty stand side by side with students in the laboratory," Lipschutz says. "Students get the mentoring attention that they often fail to get in other areas of the university."

But they also see the life of an academic researcher first-hand, and the experience can leave powerful impressions, both positive and negative. Cinda-Sue Davis, who runs Michigan's Women in Science program, says, "When I talk to [students] about going on to graduate school, they look at me like I'm crazy. They say, 'Who would want a life like that?'"

In Maddock's lab, Vici Blanc, a 23-year-old Ph.D. student, is already rethinking her decision about an academic life. "It's a lot of work. I understand that it's really rewarding. But I want a personal life. I want to be able to go home at night, to see my family if I have one, to see my friends. I want some time for play and time for myself."

Graduate student Laura Kakuk loves science but says she doesn't have the kind of personality a professor at a research university must have. To Kakuk such professors are people who must be eternally "on," ever ready to promote and defend their work in social and academic arenas. "I just don't have the right kind of personality for it. It's very, very, very competitive," says Kakuk, who is exploring other career options.

Jennifer Skidmore stands in stark contrast to Kakuk and Blanc. At 20 she is still working on her undergraduate degree but already is determined to head toward graduate school

"A lot more goes into the job of teaching than most people ever know."

and a life in academia. "I had never considered an academic life until I got to this lab," she says. Skidmore has seen the demands of Maddock's life but is not deterred from pursuing a similar dream. A big reason is Janine Maddock's zest for the career she has chosen.

"I have such incredible respect and admiration for Janine," Skidmore says. "I wouldn't want to do it the way she does it. But I respect the process of asking questions, the curiosity, the going toward a goal."

Maddock is neither surprised nor sorry that the way she lives might discourage others from pursuing similar work. "It's a hard job, and they need to see that. But they also need to see that I love this job, and I wouldn't trade it for anything."

Her NIH grant deadline might have passed for a while, but Maddock is still in her laboratory until midnight at least two nights a week. Along with the demands of teaching, mentoring, and advising, she is trying to find the time to be a scientist again, doing her own work at the bench. "My life is exactly as I predicted," she says. "This is the worst year of my life in terms of work and productivity."

Yet she also knows that her situation is transitory. "It's going to get better. It's going to get easier. Not everything will always be this new. This is just a rite of passage I need to go through."

A few months later Maddock's words prove prophetic when she receives an ACS junior faculty award. The award—$30,000 a year for three years—recognizes her potential as a scientist as well as her specific research plans.

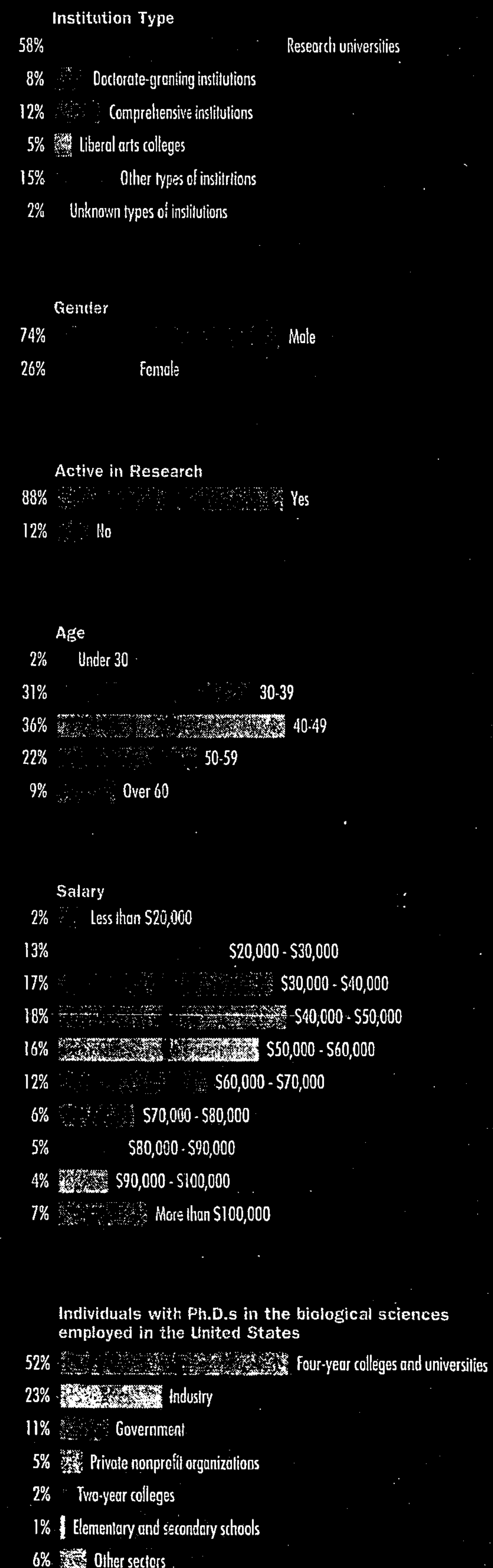
"To say she is happy about this," says a friend, "is sheer understatement. She's had a hellish winter and had just about given up hope when she got the call."

Maddock laughs that now "I may actually get a paycheck this summer." The award will make it easier for her to work in the laboratory and think about teaching, to bake cookies with her children, and to revive her NIH grant proposal. "It's really nice to get a pat on the back," she says. "It confirms that the University of Michigan made the right choice when they hired me. I don't know how to explain why I do this except that I love it."

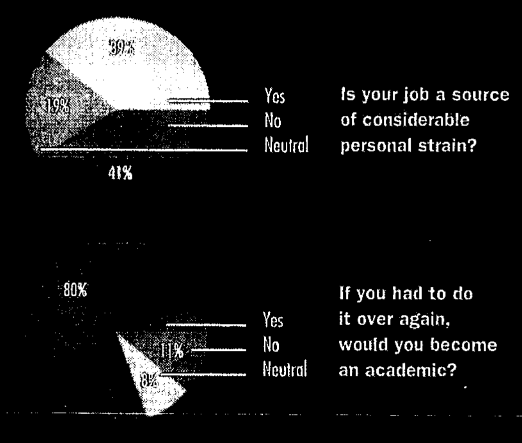
Biology Faculty Members: A Statistical Portrait

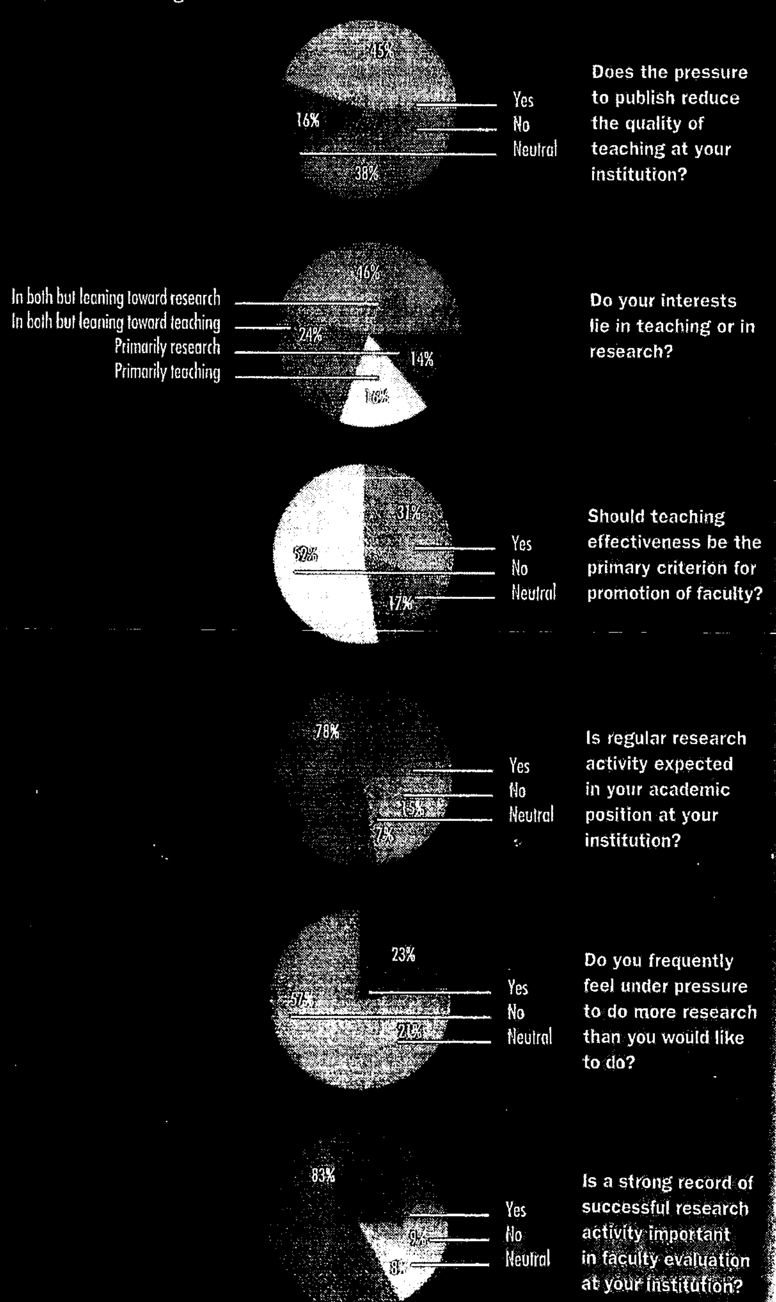
How many Ph.D.-level biology faculty members are there in the United States, and how can they be characterized? One way to find out is through the Survey of Doctorate Recipients conducted every two years by the National Research Council's Office of Scientific and Engineering Personnel.

The most recent survey of doctorate holders in the United States for which data are available was in 1993. It estimated that there are 47,700 people with Ph.D.s in the biological sciences who are employed in four-year colleges and universities. They have the following characteristics, as expressed in percentages:



The Carnegie Foundation for the Advancement of Teaching carried out a separate survey of faculty members from all types of institutions. The survey asked a nationally representative sample of faculty members a broad range of questions about their careers. Faculty members in biology departments who answered the questions gave the following responses. The percentages may not add to 100 because of rounding.





Teaching and Research at a Small College

Across Michigan in the lakeside town of Holland, Hope College biology professor Harvey Blankespoor also is putting in long hours to balance research, teaching, and service to the college. But expectations are different at small liberal arts colleges, even if the workload is not.

A Christian liberal arts school, Hope College enrolls about 2,900 students and boasts a record of sending nearly one-third of its graduates to professional and graduate schools. Blankespoor, who was named 1991 National Professor of the Year by the Council for the Advancement and Support of Education, admits that he's not doing the same sort of "fast-lane research" that he might have done at a major research university. But he is convinced that the intimate nature of small colleges provides students with a high-quality education. "They have more materials and they have more attention from professors," he says.

Blankespoor estimates that he spends about 60 percent of his time on teaching, 30 percent on research, and 10 percent on service. Instead of devoting months to writing major grant proposals, he prepares less time-consuming budget requests that bring in about $50,000 a year from lake associations in Michigan to sustain his research into parasitological diseases in the United States and around the world. His target is to get one or two articles published each year in a refereed journal. Without graduate students, postdocs, or full-time technicians, he works with four to seven undergraduates on various research projects.

According to Blankespoor, professors at Hope College may spend their time differently than professors at research universities, but they are still expected to do everything. He begins his workday at 5:30 a.m. and often does not finish before 9 p.m. "You have to blend it all," he says. "You can't be just a good teacher or just a good researcher."

Hope College professor Harvey Blankespoor

CHAPTER 5

EXPANDING THE TALENT POOL

The future diversity of America's work force can be seen in the faces of its children. Today, ethnic groups considered minorities make up about one-third of elementary school children. By the year 2030, according to Census Bureau projections, they will constitute more than one-half. Shortly after the year 2050, minorities collectively will make up the majority of the U.S. population.

Biology has been more successful than many other sciences in enrolling African American, Hispanic, and Native American students as undergraduates. Yet the number of these students who major in biology remains uncomfortably low. Of the 52,314 bachelor's degrees awarded in biology in 1994, only 2,980 (5.7 percent) went to African Americans, 2,901 (5.5 percent) to Hispanics, and 248 (0.5 percent) to Native Americans. The numbers of underrepresented minorities who major in biology have risen over the past decade, however, especially during the past few years.

Progress has come much faster for women, who now receive more than half of the undergraduate degrees in biology. Like minorities, however, women still hold relatively few senior faculty positions, making role models limited. The social pressures on women also can be more intense, particularly when it comes to balancing family and professional obligations. And women in biology are in many ways still pioneers. "If you're a biology major, you're taking courses in chemistry, mathematics, and physics, and women remain severely underrepresented in those classes," says Marsha Lakes Matyas, who has studied retention issues in science education and is the education officer at the American Physiological Society. Because of these and other factors, the attrition rate for women in undergraduate biology is significantly higher than for men.

Nonetheless, some colleges and universities have been remarkably successful in attracting large numbers of women and minorities to biology. How do they do it? This chapter begins by profiling four institutions that offer a number of answers:

Student Kathy Bancroft and adviser Ted Bartlett collect plant samples near Fort Lewis College in Colorado.

Kathy Bancroft moved to Colorado so her two sons, Harmey (above) and Franco, could experience the culture of their father's tribe.

- Fort Lewis College, a small liberal arts college in Durango, Colorado, where the biology and chemistry departments have teamed up to draw a significant number of Native American students into the sciences.
- Xavier University of Louisiana in New Orleans, which sends more African American students to medical school than any other college or university.
- The University of Texas at San Antonio, where faculty members have focused particular attention on Hispanic students.
- Wellesley College outside Boston, where a disproportionate number of the nation's women scientists received their undergraduate degrees.

Other institutions also graduate large numbers of women and minorities in the biological sciences. Furthermore, the steps described in this chapter can benefit all students, which is an important consideration as institutions examine their affirmative action policies. But the four institutions profiled here, along with a number of others discussed in the second half of the chapter, have discovered some important lessons about what it takes to attract women and minorities to biology—and to help them succeed.

SEEING STUDENTS AS INDIVIDUALS

Kathy Bancroft had several reasons for studying biology and chemistry at Fort Lewis College. Free tuition for Native American students was a big incentive. The fact that she lives in nearby Cortez, Colorado, was a plus, too.

But the biggest factor in attending Fort Lewis in her late 30s, Bancroft recalls, was her feeling of not being alone.

Two decades earlier, Bancroft, who is a member of the Long Pine Paiute–Shoshone Reservation of California's eastern Sierra Nevadas, started her undergraduate education as one of very few Native Americans at a large research university in California. She lasted less than two years in the pre-med program before rushing back to the familiar embrace of her Sierra Nevada homeland. A few years later she moved to the Four Corners region—where Colorado, New Mexico, Arizona, and Utah converge—so that her two young sons could experience the culture of their father, who is a member of the Ute tribe.

It's a land of open range and towering geological formations that has become a familiar backdrop for Western movies and landscape calendars. It's also a place of small, tightly knit communities and tradition-laden Indian reservations where Bancroft felt understood and accepted.

"It was so impersonal before," she recalls. "What scared me about it was that the classes were so large, but there really wasn't anybody that you could ask if you had questions."

Personal attention is one of the keys to Fort Lewis's success in the sciences. Nestled in the mountains of southwestern Colorado, with a view of Durango, the winding Animas River, and the snowcapped La Plata mountains, Fort Lewis is a part of the Colorado State University system. But it is also a liberal arts college with a student population of just over 4,000. The personal attention made possible by its small size is a big advantage for minority students—including the 500 or so Native Americans in the student body.

Free tuition, a product of a 19th-century treaty, is just one incentive Fort Lewis offers to

Native Americans. The college begins recruiting from the 25 reservations within 150 miles of campus as early as the fifth grade. The biology and chemistry departments work closely together on recruitment and retention issues, using not only faculty members but also current and past students. Dean Duran, a 1994 Fort Lewis chemistry graduate who is Hispanic, was hired by the college to serve as campus liaison to nearby reservations. Several times a month he travels to Native American communities in the Four Corners area to talk with students in grades 6 through 12.

"The kids can see that I studied mathematics and chemistry and that I'm successful," says Duran. "It removes a lot of the fear factor for them. So many kids are afraid of making mistakes. But research is about making mistakes and investigating the new questions they raise."

The recruiting does not end once a student has decided to enroll at Fort Lewis. Every incoming freshman with promising grades and achievement test scores receives a personal letter from chemistry professor John Ritchey touting the career possibilities made available by studying science. Then, once classes have begun, biology and chemistry faculty members try to get to know their students, both in the classroom and in extracurricular help sessions and social events.

"I have a Native American student in my introductory chemistry class who is on the verge of failing," says Ritchey. "I made a point to introduce myself to her in the beginning of the semester. Now I've written a note to her asking her to come see me so we can figure out how she can do better. I can't be sure she won't fail. But she won't slip through the cracks."

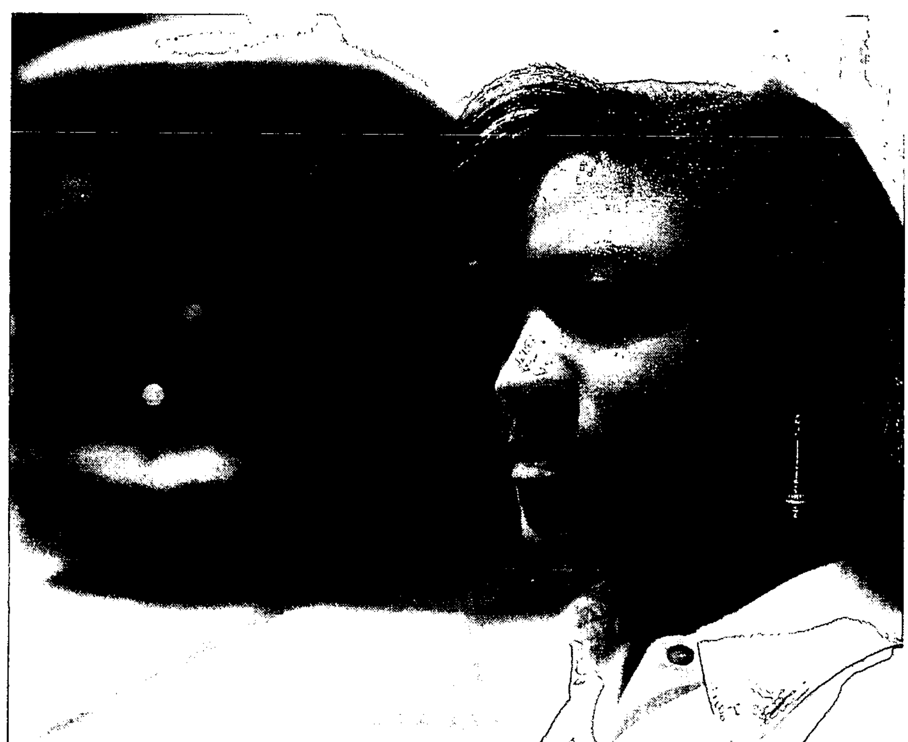
The personalized attention continues as students progress. Faculty members encourage students to get involved in research and to travel during the summer to take advantage of research opportunities. They also try to get upperclassmen to help underclassmen and area high school students, in part to attract new students to the program.

This attention has been paying off. "Ten, fifteen years ago we almost never had a Native American graduate in biology," says biology professor Preston Somers. Now Native Americans represent 10 to 15 percent of the biology department's approximately 45 majors per year, and the numbers are up sharply in recent years. Furthermore, Native Americans who majored in biology at Fort Lewis and went away to graduate school several years ago are now approaching the end of their postdocs. "We'll soon be in a position to consider hiring people who graduated from our program," says Somers.

PAVING A PATHWAY FOR SUCCESS

As is the case at Fort Lewis College, early and continuous intervention is the key to success at Xavier University of Louisiana. But the biology department's principal goal—preparing young African Americans for medical, dental, and pharmacy schools—results in different kinds of interventions.

Wedged between an interstate highway and a canal in New Orleans, Xavier mostly enrolls African American students from nearby parishes. Upon entering the university's new science building—which opened in 1988 to replace the World War II



Undergraduate Renee Markham assists middle and high school students who attend Xavier's summer science programs in New Orleans.

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barracks that previously held the science labs—students encounter rows of photographs of the previous year's graduates with a listing of where they were accepted to professional or graduate school. The message is unmistakable: stick with it and your photograph will be here, too.

But Xavier cannot wait until its students arrive at college to prepare them to be physicians and scientists. By then many would be too far behind to catch up with biology majors elsewhere. So Xavier starts working with prospective students much earlier.

The university's main connection to high school students is through its Summer Science Academy. The academy begins between eighth and ninth grades with a two-week program known as MathStar. More than 100 students from in and around New Orleans attend class seven hours a day, learning the skills they will need to succeed in high school mathematics. Daily quizzes test the previous day's progress, and students have at least two hours of homework each night.

The next summer students attend BioStar, a three-week program to prepare for high school biology. The summer after that is ChemStar, another three-week program. Finally, the summer after their junior or senior years, 150 to 200 high school students enter SOAR (Stress on Analytic Reasoning), a residential program on the Xavier campus. For four weeks they attend class from 8 to 5, with two hours of mandatory study hall on Sunday through Thursday evenings. Most of each morning is devoted to laboratory work, where students gain experience in chemistry, biology, and physics. "That is a very important component of the program," says biology professor and dean of arts and sciences Deidre Labat. "It's the first time many of those students have ever been into a lab."

All of the summer programs are carefully structured to mix academics and social activities. After a morning of laboratories and lectures, students break into groups that are often led by a Xavier undergraduate. The group leaders organize academic and social competitions, such as talent shows and group performances, to promote peer support. They also phone participants who are late or absent, provide tutoring for those who need special help, and serve as role models.

Renee Markham, who went through the entire academy sequence and later served as a group leader while a Xavier undergraduate, emphasizes that the role of the group leaders is to make the summers fun as well as challenging. "We try to balance it out," she says. "It is the summer, so you can't study all the time." The groups both compete and cooperate, preparing students for the mix of social pressures they will face in college. "It's always friendly competition," says Markham, "but enough so you want to be number one."

The same combination of academic rigor and social support follows students into their first year at Xavier. (The SOAR program serves as a powerful recruiting tool for Xavier, with more than three-quarters of its participants matriculating at the university.) Freshmen at Xavier spend twice as much time in mathematics and science courses as most freshmen elsewhere. To help them cope, the school has an intensive tutoring program in these subjects and a writing center for help with papers. Faculty members also encourage freshmen in chemistry and biology to join or form study groups.

Reaching Out to Older Students

The fastest-growing segment of the undergraduate population is students over the age of 24, according to the U.S. Department of Education. Many of these students are women and minorities, and all face an unusual set of pressures in going to college.

"The university atmosphere is usually dictated by teenagers, everything from the music to the social life," says biology professor Terry Johnson of Kansas State University. "Older students tended to come on campus and quickly leave. They never get to know about each other."

Kansas State University specializes in providing support for nontraditional students, who now make up more than 15 percent of the university's student body. A particular focus is single parents pursuing health care careers. "These students are well motivated," says Johnson, who directs the support program for nontraditional students, "but many have difficulties." The university's biology division provides financial help, child care, faculty and peer support, and monthly seminars on such topics as campus resources, career preparation, and stress management.

About 25 students are enrolled in the program, and another 60 or so take advantage of various resources. "It's had a remarkable effect," Johnson observes. "They babysit for each other. They help each other out."

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Andrew Martinez at the University of Texas at San Antonio talks with students Joanna Gutierrez (left) and Ana Treviño (center).

"We try to get students to buy into the peer support network," says chemistry professor and pre-med adviser JW Carmichael. "The way we do that is by integrating social and academic life. We have parties and dances and go to football games—we just don't do it before a big organic chemistry test."

For Xavier the formula works. More than half of its approximately 2,000 undergraduates major in mathematics or science. In recent years 20 percent of its graduates—about 100 students a year—have gone to medical, dental, or graduate school, and over 90 percent of those students have received or are on track for receiving their professional degrees.

CHALLENGES AT A BIG SCHOOL

At the University of Texas at San Antonio (UTSA), a focus on recruitment and retention occurs in the context of a much larger institution. Located on the far northwest side of San Antonio, UTSA has an enrollment of about 15,000 undergraduates and 2,400 graduate students. More than half of San Antonio's population is Hispanic; another 7 percent is African American. At UTSA, Hispanics make up 36 percent of the student population, and nearly all are from the local area.

Many minorities come to the university wanting to major in biology but are overwhelmed by introductory courses in science and mathematics. According to Andrew Martinez, professor of life sciences at UTSA, "It's during the first two years of the major that we lose many of the talented and promising minority students. So we spend a lot of our effort on retaining freshmen and sophomores."

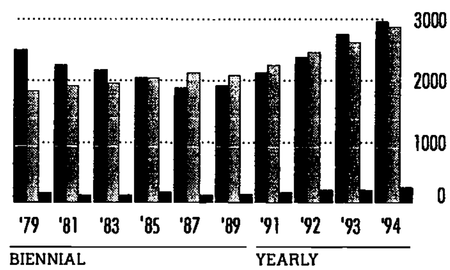
To keep lower-division students from leaving biology, UTSA has sought to do many different things well. For example, new laboratory courses for beginning biology students emphasize real-world applications, such as using electrophoresis to solve forensics problems or working with enzymes to study digestion. "The experiment is designed to be about something they can relate to," says Martinez. "Even a simple thing such as enzyme digestion has an important principle behind it."

UTSA also has sought to involve students in research projects as early as possible. Each year biology faculty members recruit a small group of freshmen and sophomores—including a significant percentage of minorities and women—to work in faculty laboratories. The intent is to get students working on independent projects right away, and the approach has been succeeding, with a number of students attending scientific meetings each year to present the results of their projects. "They come back with a new enthusiasm," says Martinez. "Even for those who decide science isn't for them, they become better students because their confidence in their academics goes up."

A special focus of the biology department has been Hispanic women. In many Hispanic families, Martinez notes, women traditionally have been expected to stay at home, although cultural expectations are slowly changing. UTSA has been recruiting women in high schools and community colleges, getting them into research laboratories, and encouraging them to do summer research.

Cynthia De Leon, now a Ph.D. student in the neurosciences program at the Baylor College of Medicine in Houston, was one of the Hispanic women recruited into a laboratory as a sophomore at UTSA. Born and raised in a small town in South Texas, she had never been as far from home as San Antonio. But her experience in the lab allowed her "to

Bachelor's Degrees in Biology Received by Underrepresented Minorities



■ African American
□ Hispanic
■ Native American

Note: 1983 data are estimated
Source: U.S. Department of Education

interact with students on a research track who were really motivated," she recalls. A subsequent summer research project at the University of California at San Diego further sparked her interest in the neurosciences. "If it wasn't for those programs, I wouldn't be where I am today," she says. "They enabled me to go a lot farther than I ever would have been able to on my own."

ESTABLISHING NEW TRADITIONS

Wellesley College has turned the retention of women in the sciences into an art. About a quarter of Wellesley's students graduate with science degrees. In a recent National Science Foundation study of women who earned science or engineering doctorates between 1985 and 1990, more received their bachelor's degrees from Wellesley than from any other liberal arts college.

A commitment to the sciences has taken a tangible form at Wellesley. In 1977 the college opened a strikingly modern science building that was added onto an existing laboratory building. The new building brought all of Wellesley's science departments, formerly scattered across campus, together under one roof. In the soaring atrium that connects the old and new buildings, faculty members and students mingle across disciplines and generations.

At the heart of the science building are its teaching laboratories. Wellesley kept the labs small, ensuring one-on-one contact between students and faculty. "Wellesley has really clung to its labs, even though some institutions have dropped them because they're too expensive or too much bother," says Andrew Webb, a professor in the biology department. "But we think there's no replacement for getting your hands wet."

Beginning with its introductory labs, which are required for all students, the science departments pull students toward more advanced work. "We look at our labs as a progression of hands-on experiences," says professor Mary Allen. "They're an essential part of learning science, so even in beginning courses we have students doing fairly sophisticated projects."

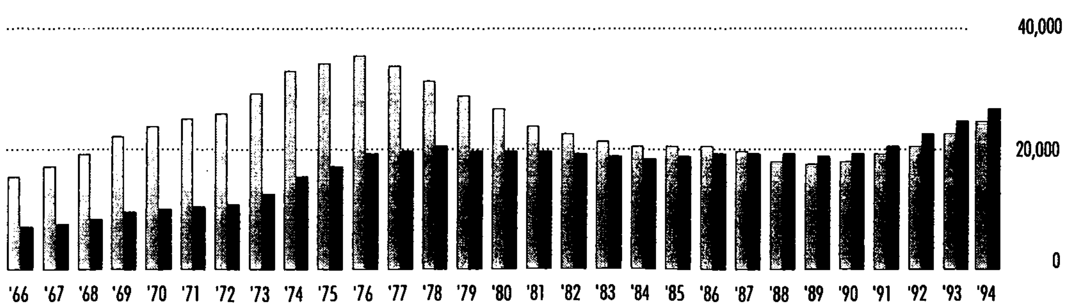
By their sophomore and junior years, increasing numbers of students are participating in research projects. With no graduate students on campus, faculty members involve undergraduates extensively with research projects, and more than half of the faculty's publications have student co-authors. More than half of the biology majors do research by the time they graduate.

These experiences figure prominently in stories told by students such as Jennifer Mills, who came to Wellesley from Mannington, West Virginia. After taking her first couple of classes in the sciences, "I didn't think I had what it took," she recalls. "Everyone else seemed so much better prepared."

But the summer after her sophomore year Mills began to do research on the effects of brain lesions in mice in the laboratory of a professor she admired, and her doubts quickly disappeared. "I stayed in science because I found a professor who took me under her wing and expressed an interest in me," she says.

This individual interaction with women scientists characterizes the study of biology at Wellesley. Alumnae often return to the campus to talk about their careers in science, giv-

Mary Allen and students overlook new computer center in Wellesley's science building.



Source: U.S. Department of Education

Bachelor's Degrees in Biology Received by Men and Women

Rather than fighting over a small pool of students, colleges and universities have to help expand the pool.

ing students a chance to see how Wellesley graduates have combined science with other responsibilities. Students doing research in the summer go on field trips to nearby industrial laboratories, where they can meet with female scientists.

The strong links formed at Wellesley often last well beyond college. Says psychology professor Steve Schiavo, "It's very common that when students get out in the real world, they will call a professor they worked with here at Wellesley to talk over a problem. That's been an unanticipated consequence of getting students involved in research early in their college years."

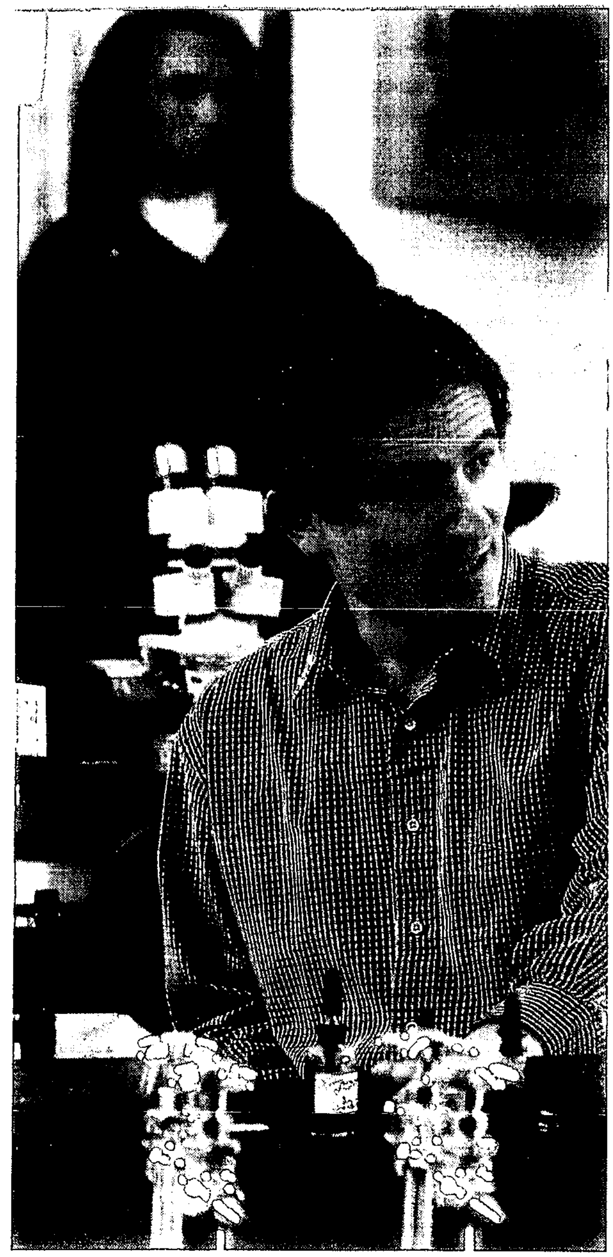
A KALEIDOSCOPE OF APPROACHES

Faculty members involved in these programs agree there is no magic strategy for attracting women and minorities to biology. But they point to several initiatives that, in combination, produce results.

Start early. If colleges and universities want to achieve diverse student bodies, they cannot wait for high schools to produce a steady stream of qualified applicants. Rather than fighting over a small pool of students, colleges and universities have to help expand the pool.

Many programs aim young. "We try to find kids in junior high and provide them with academic reinforcement every summer so that they can achieve at the level they'll need to if they're going to achieve success in biomedical sciences," says Xavier's Carmichael. In fact, Carmichael would like to target even younger children, since many African American males already are turned off to science by junior high.

Other institutions engage in outreach programs specifically tailored for the precollege students in their areas. Oklahoma State University in Stillwater organizes science day camps at elementary schools in Oklahoma, which is the home of more Native Americans than any other state in the nation. It also prepares "footlockers" of resource materials for teachers to use during the year and holds month-long science summer camps for promising high school students from nearby tribes.



At the University of Puerto Rico Mayaguez Campus, the "Science on Wheels" project travels by van along the western coast of the island, visiting rural towns where schools lack modern laboratory equipment. The purpose of the visits is to demonstrate basic scientific principles to precollege students and to train precollege teachers to do hands-on laboratory exercises in their classrooms. "It's very cost effective," says Juan G. González-Lagoa, associate director of the Resource Center for Science and Engineering on the Mayaguez campus. "This program has made it possible to reach many more students and teachers than any other activity."

Of course, not all students involved in a college-initiated outreach program will matriculate at that institution. But many do, and the programs as a whole can help significant

numbers of young women and minorities nationwide become more familiar with the content and expectations of college-level science. Between 1988 and 1995, for example, campuses supported through the HHMI undergraduate program reached more than 55,000 students and 16,000 teachers at the precollege level.

Provide lots of support. Undergraduate science can be a forbidding environment for some students, especially those unfamiliar with the culture of science. Many students have never encountered working scientists before coming to college. They may be intimidated by the pace of the work and the complexity of equipment and procedures in the lab. The scientific jargon spoken between faculty members and older students also may discourage them.

Making students feel welcome is not complicated, faculty members say. The most important step is simply getting to know them outside the lecture hall, whether in discussion sections, laboratories, or social gatherings. For instructors to greet students by name and take a moment to speak with them one on one makes them feel like they belong in this new setting. "Being a minority myself, I know that something that simple can turn out to be very important to minority students," says UTSA's Martinez. "After a while, they assimilate."

Individual attention makes it much easier to know when a student is struggling. At Xavier, nearly constant quizzes during the freshman and sophomore years let faculty members know when someone is floundering. Mandatory weekly meetings with advisers are another way to keep tabs on students, who need frequent and honest assessments of their performance.

Students also need academic advising to ensure they take the right courses and keep on track to a degree and good job. Sometimes this advising covers financial or personal difficulties or at least provides guidance about where to get help for non-academic problems.

In some institutions many of these forms of support are tied together in comprehensive programs. At California State University–Los Angeles, the Minority Science Program specifically seeks to improve the retention rates of minority students in freshman science and mathematics courses. The 50 or so students in the program, representing a wide range of ethnic groups, receive frequent advising and counseling. They work in small groups to develop skills like problem solving, writing, speaking, and effective studying, with upperclassmen serving as facilitators. "The meetings are not tutorials," says biochemistry professor Raymond Garcia. "Tutors can't take an exam for you. So we try to get students to work through problems for themselves."

Encourage students to help each other. Faculty members sometimes overlook the most important form of support available to a student who is struggling: other students in the program. Friends and classmates can be invaluable sources of assistance and advice on both academic and personal issues.

At the University of California–Berkeley, more than 200 undergraduates, many from

HHMI investigator Corey Goodman (foreground) works with students through the Biology Scholars Program, which provides support for minorities and other undergraduates at the University of California–Berkeley. John Matsui (center) directs the program.

RESOURCES

The **American Indian Science and Engineering Society** (AISES) sponsors over 130 chapters on college campuses in the United States and Canada, provides scholarships to Native American students, holds an annual conference and career fair, and publishes *Winds of Change* magazine. Address: 5661 Airport Blvd., Boulder, CO 80301-2339. Telephone: (303) 939-0023. Fax: (303) 939-8150. Internet: aiseshq @spot.colorado.edu.

ASPIRA, Inc., is a national organization devoted to developing leadership and educational opportunities for Puerto Rican and Latino youth. It conducts a National Health Careers Program for high school and college students. Address: 1444 I St., N.W., 8th Floor, Washington, DC 20005. Telephone: (202) 835-3600. Internet: aspira1@aol.com.

The **Association for Women in Science** (AWIS) is a nonprofit organization committed to achieving equity and full participation of women in all areas of science and technology. Members include students, teachers, practitioners, and policymakers. AWIS publishes books, a magazine, and other documents; holds an annual meeting in conjunction with the annual meeting of the American Association for the Advancement of Science; and has local chapters across the country. Address: 1200 New York Ave., N.W., Washington, DC 20005. Telephone: (202) 326-8940. Internet: awis@awis.org. World Wide Web: http://www.awis.org/~awis.

The **Association of American Medical Colleges,** through its Project 3000 by 2000, is working to increase the number of underrepresented minority students enrolled in medical schools. The project publishes directories of programs for minority high school and college students interested in the health professions. Address: 2450 N St., N.W., Washington, DC 20037-1126. Telephone: (202) 828-0584.

The **Leadership Alliance** is a consortium of 23 institutions of higher learning focused on increasing the numbers of minorities with doctorates in all disciplines. The alliance supports undergraduate research, faculty development, and international programs and provides financial support for underrepresented minority students pursuing graduate study. Address: Brown University, Sayles Hall, Room 15, Providence, RI 02912. Telephone: (401) 863-1474. Fax: (401) 863-2244.

The **Quality Education for Minorities Network** (QEM) works with individuals and groups to develop policies and support for education opportunities for minority students. It does not directly fund programs serving youth but knows who is doing what throughout the country. Address: 1818 N St., N.W., Suite 350, Washington, DC 20036. Telephone: (202) 659-1818. Internet: qemnetwork@qem.org. World Wide Web: http://qemnetwork.qem.org.

The **Society for the Advancement of Chicanos and Native Americans in Science** (SACNAS) helps its members pursue jobs, grants, summer research opportunities, and other resources. National conferences are designed to encourage Chicano and Native American undergraduate science and engineering students to pursue graduate education. Address: University of California, 1156 High St., Santa Cruz, CA 95064. Telephone: (408) 459-3558. Internet: sacnas@cats.ucsc.edu. World Wide Web: http://vflylab.calstatela.edu/sacnas/www/sacnas.html.

The **Howard Hughes Medical Institute** has produced two free videotapes, "Not So Wild a Dream" and "The Xavier Experience," that explore ways of attracting minorities to science and helping them succeed. Address: Office of Communications, HHMI, 4000 Jones Bridge Road, Chevy Chase, MD 20815-6789. Telephone: (301) 215-8855. Fax: (301) 215-8863. Internet: commpub@hq.hhmi.org.

minority groups, work together regularly through the Biology Scholars Program. They study in groups led by undergraduate tutors, attend presentations by scientists from the campus and elsewhere, carry out research, and present their results. Minority graduate students meet with undergraduates, and upperclassmen assist incoming students. Senior Alissa Myrick calls it "the new old boys' network."

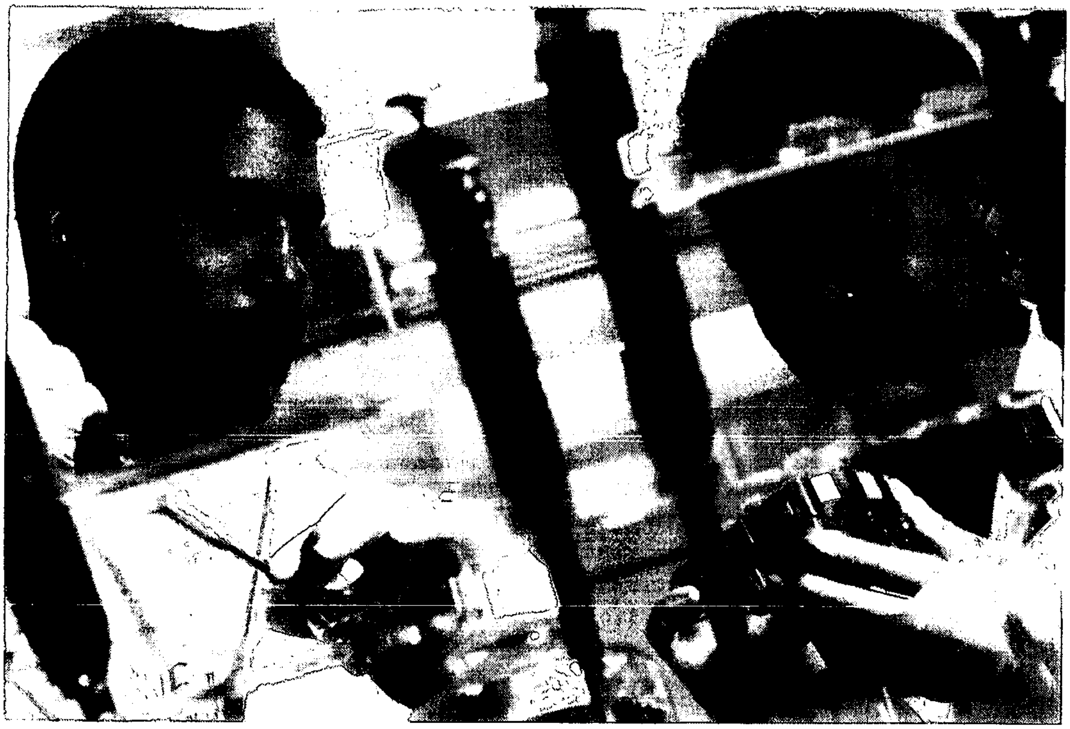
Brooklyn College of the City University of New York also has a diverse student body. Many of its biology students participate in a peer tutoring program, with upper-level science majors assisting less advanced students in courses with high attrition rates.

All of the programs profiled here seek to build this sense of community. At UTSA, senior science majors mentor freshmen and sophomores in lab classes. At Xavier, students doing well in a course are hired as "group study coordinators" to help others. At Fort Lewis, Native American science majors are encouraged to make themselves available not only to incoming Native Americans but also to secondary school students in the summer recruiting programs.

On some campuses this sense of community extends throughout the student body. At women's colleges like Wellesley or historically black colleges and universities like Xavier, the entire campus becomes a peer group. "All of the emphasis of teaching and scholarship at Wellesley is focused on undergraduate women," says Allen.

Keep standards high. Many students arrive on campus lacking the skills needed to do well in the sciences, and the problem often is worse for minorities and women. In some cases the schools they attended earlier lacked the resources needed to challenge them. In others, students were told by well-meaning guidance counselors to take easy classes to keep their grade point averages high.

The right kind of support can help these students catch up. Xavier's motto, for example, is "standards with sympathy." Rather than weeding out underprepared freshmen and sophomores, faculty members provide extensive support to help them get up to speed. Then, in their junior and senior years, the spe-



Christopher Tubbs (left), now a graduate student at North Carolina State University, was introduced to undergraduate research during a summer program at the University of North Carolina at Chapel Hill.

cial support gradually fades, so that the students will be ready to compete with their peers in professional schools and the workplace.

Summer internships and other collaborative programs also can expose undergraduates to the settings they will encounter in future years. The University of North Carolina at Chapel Hill, for example, holds summer workshops with several of the state's historically minority universities. The workshops allow minorities to experience life in a laboratory doing research. "It opened my eyes," says Christopher Tubbs, who is now a doctoral student at North Carolina State University working on the biochemistry of sperm maturation. "I had no idea what research is about." After completing the summer program, in which students do a sequence of projects in different areas of biology, Tubbs received several scholarships that enabled him to continue doing research as an undergraduate at North Carolina Central University.

Pay competitive stipends. Many students cannot afford to work long hours in laboratories for low or nonexistent wages. At UTSA, for example, Martinez estimates that 95 percent or more of the minority students in his program must hold jobs to pay for tuition and expenses. The biology department therefore pays students appropriately for the work they do in the lab—$5,000 a year for 15-hour weeks during the academic year and full time during the summer.

"The stipend enables these students to participate," Martinez says. "We want them to devote full time to their academics. They can't have any employment that would detract from their studies."

Stipends also reinforce the notion that science is important and could lead to a career. At Fort Lewis, for example, stipends distinguish the summer program in biology from other programs and entice students to try something different. "One of the strongest things we compete against," says the college's Preston Somers, "is students' idea that they've gone to school for nine months and the summer belongs to them."

Respect social differences. Faculty members and students continue to debate whether different groups have different approaches to science. But hard experience has taught many instructors that monolithic approaches to teaching are ineffective. "It's forced us to let go of how we were taught science," says Fort Lewis chemistry professor Jim Mills. "When I went to school we were taught as a group. Here we emphasize individual attention."

For Native Americans, cultural sensitivity could mean finding alternatives to dissections for students from tribes with prohibitions against touching the dead. For Hispanic students, it can mean recognizing that today's generation of students is the first in which it is more widely accepted that students may have to leave their communities to establish careers. For African Americans, faculty members may want to take advantage of learning styles based on cultural traditions. Xavier's Deidre Labat, for instance, says many African

Two-year colleges: Much more than vocational schools

Any serious effort to attract more minority students to science must involve two-year colleges. More than 50 percent of minorities underrepresented in the sciences begin their college education at two-year colleges—and many have the ability and desire to succeed in science.

Lipton Gonzalez, for example, is a biology professor's dream. In high school he scored the maximum "5" on the advanced placement tests in biology and calculus. Now a college sophomore, he has a 3.9 grade point average and is working on a research project on how coronary bypass surgery affects platelet and neutrophil levels in the blood. But he could not afford a four-year college. Instead, he lives at home and attends the Kendall campus of Miami-Dade Community College, which charges only $471 per semester for tuition. Two-thirds of Kendall's 20,000 students are Hispanic.

"Sometimes people rag on us because we go to a community college," says Lipton, who was born in Cuba. But now he and several dozen classmates are getting the chance to prove themselves by attending free courses and carrying out research with professors at the nearby University of Miami, which also pays them stipends, covers their community college tuition, and, if they do well, invites them to complete their junior and senior years at the university tuition-free.

"I'm doing things that I've never tried before and I really like it," says first-year student Tatiana Ferreiro, who is learning to use new stable isotope techniques to study how the intrusion of saltwater affects photosynthesis rates and the broader health of freshwater plants in Florida. "The only way you can really learn about science is to experience it yourself." Betty Blanco, who is sequencing DNA to learn about genetic variation among small Florida mammals that are environmentally threatened, says, "I consider this a pathway to what I want to do next."

Their determination and performance belie any notion that scientific talent is limited to elite universities.

Most of the Miami-Dade students come from working-class families. Most hope to obtain medical degrees, but others want to become veterinarians, biomedical engineers, or geneticists. Their determination and performance belie any notion that scientific talent is limited to elite universities.

"Some community college students are among our very best students," says Merna Villarejo of the University of California–Davis, which enrolls more than 300 transfer students in biology each year. "The reasons for going to community colleges these days are primarily economic."

"Some of these kids are just wicked smart," agrees Karen Olmstead, an ecologist at the University of South Dakota who directs an outreach program for students at community and tribal colleges. Olmstead is quick to add, however, that Native American students at the University of South Dakota are nearly four times more likely to drop out than others. Support programs, she says, are essential for easing the transition for those coming from distant two-year colleges or directly from reservations.

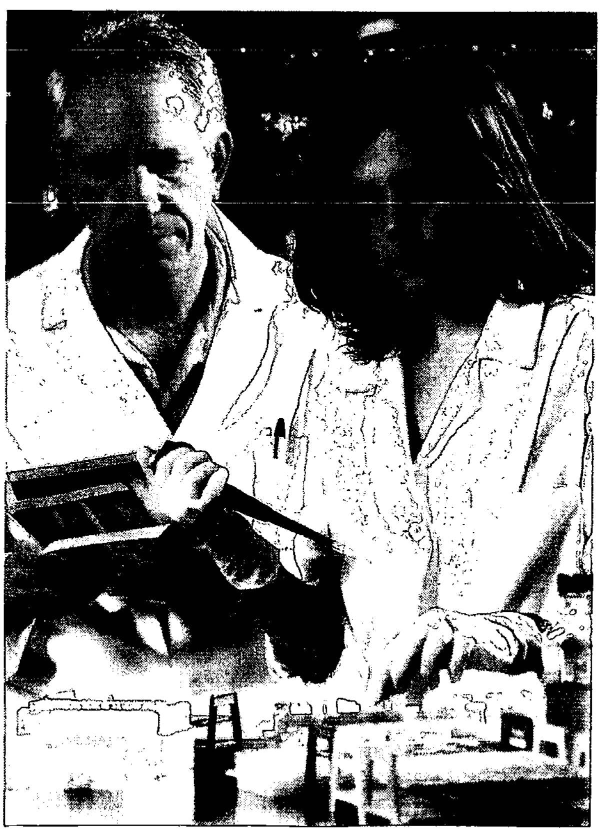
Many universities are strengthening their ties with two-year community, tribal, and technical colleges, whose size and mission vary considerably from state to state. In addition to bringing talented students on campus to study and carry out research, for instance, the University of Miami coordinates its course offerings with two-year colleges, making it easier for students to transfer, and provides sabbaticals for faculty members from two-year colleges to strengthen their skills. Many other universities have similar programs. At Arizona State University in Tempe, biology faculty members from the university and two-year colleges gather at workshops to exchange teaching ideas.

The key to such collaborations, participants say, is genuine collegiality. "People from universities need to understand that we have as much interest in science as they do," says Robert Pope, who chairs Kendall's biology department. "We just have a very different mission. If they approach us with a spirit of teamwork, they'll find cooperation. If they treat us as inferiors who haven't quite made the grade, they'll hit a stone wall."

Michael Gaines, who chairs Miami's biology department, meets often with Pope and other faculty members at Miami-Dade. He also travels regularly to area high schools to encourage minority students to take advantage of the program after they graduate. "We want to expose them to research," Gaines says, "and even get them to consider science as a career."

One student who recently joined the program is Miami-Dade's Eltanya Patterson, who carries a full load of classes, works 20 hours a week in a grocery store, is a cheerleader at Kendall, and regularly attends biology group meetings at the university. For her, as for so many other two-year college students, the biggest hurdles are not intelligence or commitment but money and opportunity. "Wherever the money is, you go," she says.

Betty Blanco, a student at Miami-Dade Community College, with her father in his barber shop in the Little Havana section of Miami (top). Blanco participates in a research project at the University of Miami with professor Michael Gaines (bottom).



Friends and classmates can be invaluable sources of assistance.

American students respond well when given opportunities to affirm verbally what they've just been taught, as in the "amen chorus" of their churches.

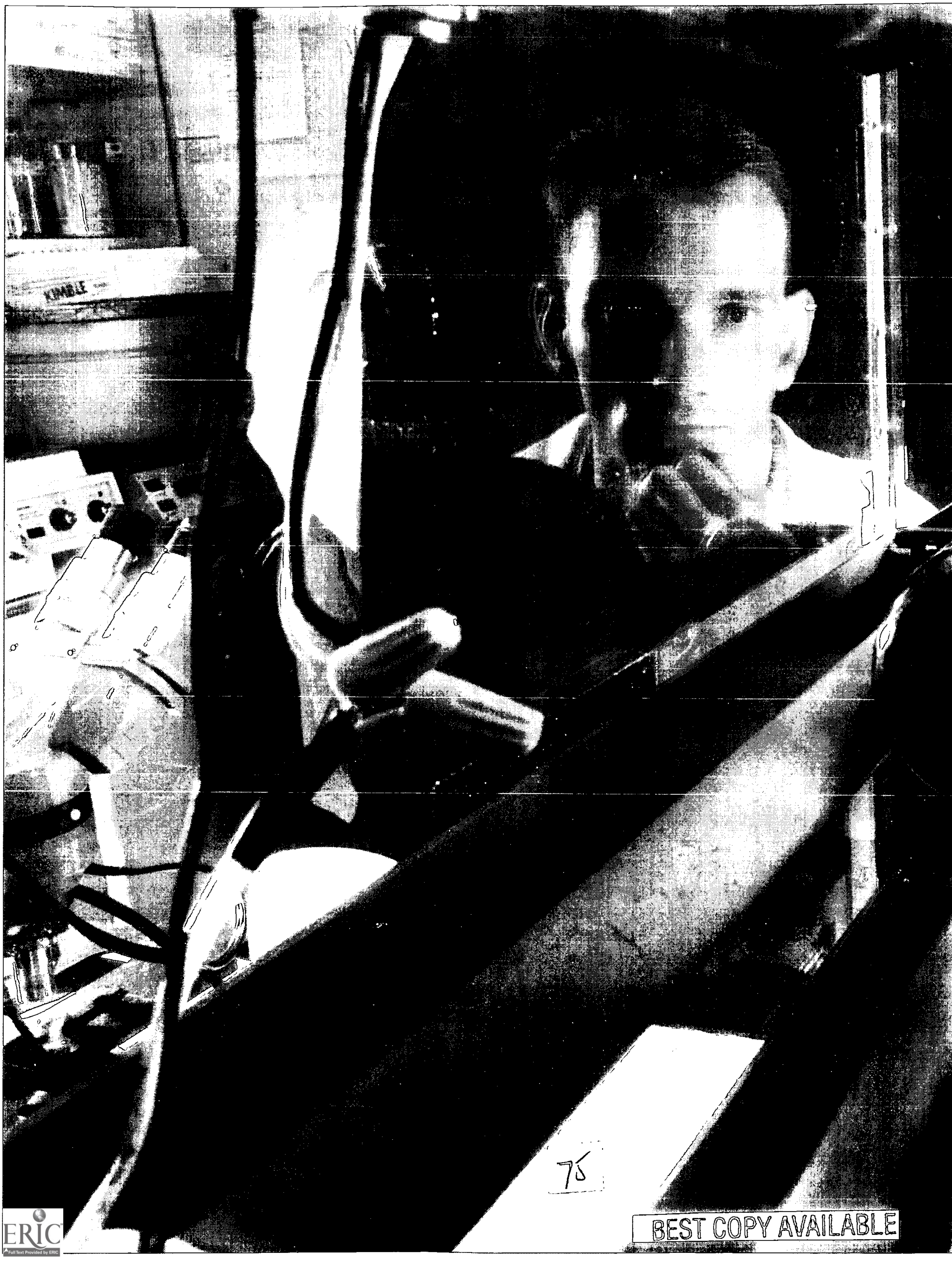
Paying attention to social differences may lead to even deeper changes. Many women and minority students, for instance, prefer cooperative forms of learning in class, as opposed to the competitive atmosphere of many traditional classes. And as more women become faculty members, other long-standing habits may fall. For example, as Harvard professors Gerald Holton and Gerhard Sonnert discovered in studying the careers of more than 800 prominent scientists, women scientists tend to publish fewer but more frequently cited papers. Such findings may affect the methods by which all biology faculty members, women and men, are evaluated and promoted.

THE FRUITS OF PATIENCE

Above all, say faculty members involved in efforts to help women and minorities, be patient. Easing the underrepresentation of women and minorities in the sciences will take sustained efforts over many years. Individual successes are important, and it is hard to predict when they will occur.

Consider Kathy Bancroft, the Fort Lewis senior who had such difficulties as a pre-med student in the 1970s. During the summer of 1995, she traveled to Stanford University on a research fellowship with Fort Lewis chemistry professor Ted Bartlett. As part of a student research team, she helped synthesize a molecule found in ginseng that contains antiviral properties. The root yields only small quantities of the compound naturally, so pharmaceutical companies would be interested in a synthesized version.

Bancroft says that working with natural pharmacological compounds fits well with her Native American heritage. But she says she is especially proud of succeeding at an undertaking that had previously defeated her. "I was surprised at how well prepared I was," she says. "I even stayed an extra week."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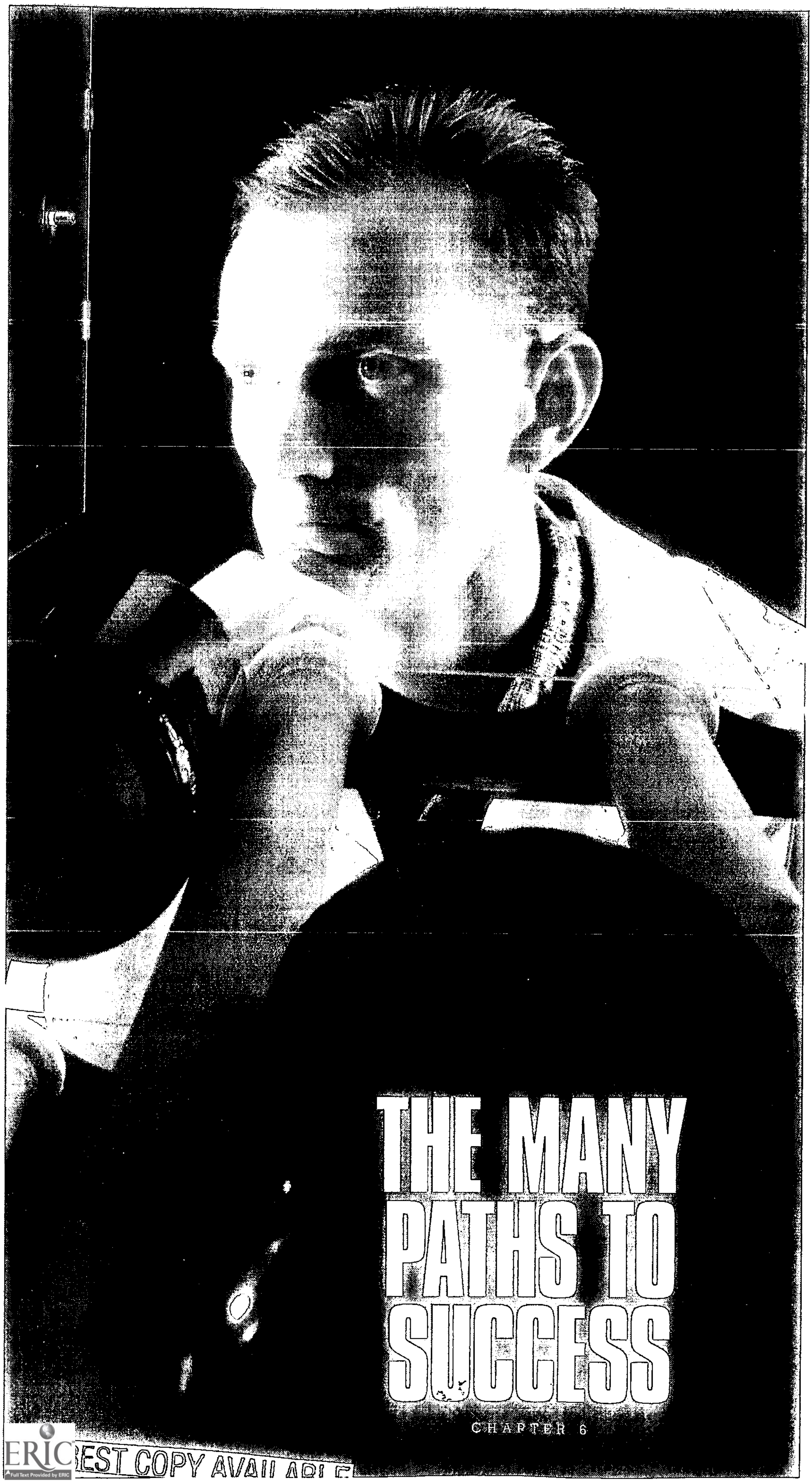


CHAPTER 6

Just as biology has found unifying themes in the function of DNA, the process of natural selection, and the dynamics of ecosystems, so biology education has been uncovering the principles that underlie effective teaching and learning. Instructors are finding that students learn more when asked to engage in critical thinking and problem solving. Changes in the workplace are highlighting the need for people to be able to communicate their ideas and work in teams. Innovative programs are demonstrating how to involve a broader cross section of young people in the sciences, especially women and minorities.

These principles are driving much of the change going on in biology education today—but change is rarely easy. Faculty members and students alike can resist unfamiliar approaches to teaching and learning. Institutional inertia

As an undergraduate at the University of Arizona, Tony Rhorer discovered the importance of research.

can stymie educational reforms. Biology is advancing so quickly that just keeping up with the field can be a full-time job.

Yet the rapid growth of biological knowledge is itself a powerful force for change. Instructors know they can no longer cover everything; instead, they are increasingly focusing on concepts that cut across scientific fields. Biology is building bridges to chemistry, physics, mathematics, information science, and other disciplines, requiring that its students become well grounded throughout the sciences. Classroom and laboratory instruction are emphasizing the flexibility that students need to master rapidly advancing specialties and techniques. And as biology itself assumes an increasing prominence among the sciences, biologists are realizing that their responsibilities have changed. They must produce not just the doctors and research scientists of the future but also a biologically literate citizenry.

Each biology department is unique, with its own traditions, personnel, and students. Yet all are grappling with common problems. This final chapter looks at several steps that have emerged as especially important for improving undergraduate education. It also focuses on a specific question: How can change move beyond individual educators to include entire departments and campuses, leading to a new set of expectations for biology education nationwide?

INVOLVING UNDERGRADUATES IN RESEARCH AT THE UNIVERSITY OF ARIZONA

Students learn with their hearts as well as their minds. When the undergraduate experience works, it gives both direction and meaning to life.

Tony Rhorer, now in his first year of medical school at Duke University, underwent such an experience in college. The summer after his sophomore year at the University of Arizona, he began doing research on the toxicity of trichloroethylene (TCE) and chromium on thin slices of rat liver. After World War II, firms in South Tucson dumped large amounts of these chemicals into shallow holding ponds, where the chemicals seeped into local wells. Rhorer's research was designed to explore the connection between the contaminated well water and clusters of birth defects and cancers that had appeared among the residents of South Tucson.

The research was technically challenging, and Rhorer spent months learning how to prepare the tissues, get them to grow in culture, and interpret complex toxicological outcomes. Yet the research always seemed somewhat abstract to him until he got a call from Carol Bender, the undergraduate research coordinator at the University of Arizona, asking him if he would be interested in visiting some local high schools to describe his work.

Rhorer traveled to Sunnyside High School in South Tucson, where he talked for a half hour about his research. "The response was amazing," he says. Many of the students told him right after the talk that they had family members with health problems related to TCE. "Some of them thanked me for doing this research. That's something you can't get in a regular class."

Rhorer undertook his research through the Undergraduate Biology Research Program at the University of Arizona. Initially designed to get more undergraduates into laboratories, the program has had a much broader impact, promoting widespread changes in teaching styles, curricula, and outreach programs.

The Undergraduate Biology Research Program began at Arizona in 1988 when the head of the biochemistry department then, professor Michael Wells, resolved to "hook" more students on science by exposing them to research. As at other research universities, Arizona undergraduates long had been wheedling their way onto research teams as glass washers and then climbing the research ladder. Wells decided that undergraduates—and women and minorities in particular—needed a more formal way of becoming involved.

The first year of the program, 19 students expressed interest. Instead of writing a research proposal, they met with faculty members to find common interests and a congenial fit. The students started their research jobs in the summer, working full time and learning their way around the lab. All earned salaries, without which many would have needed other summer jobs. Half of the funding for the program came from extramural sources, the other half from faculty research grants.

The next year three times as many students applied for the program, and twice as many again the year after that. "In our wildest dreams, we didn't expect the program to get this large," says Wells. Today, about 120 students do research in the summer, and about 100 during the school year. To date, 53 percent of the students have been women, and 14 percent have come from minority groups underrepresented in the sciences.

Accommodating that many students in the laboratories of the biology faculty members would be difficult even at a large research university like Arizona. So the founders of the program took a different tack. They asked faculty researchers in the medical school, agricultural school, and other departments to join in taking on undergraduates.

The response was overwhelming. More than 200 faculty members in the life sciences, including a majority in each department, responded to Bender's request for volunteers. Faculty members with one undergraduate in their labs asked for more. "This is the way we want to teach, one on one," says assistant biology professor Judith Bronstein. "It's not like we would prefer to teach classes of 500 students."

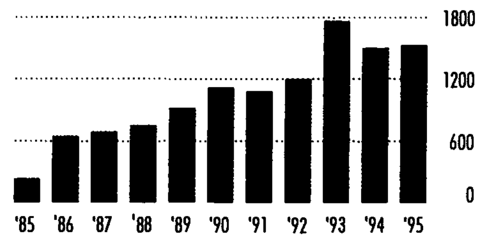
The program is not limited to upperclassmen; many students start the summer after their first year. Faculty members have found the lower-division students to be every bit as capable as the juniors and seniors. In fact, in the evaluations of undergraduate researchers filled out by faculty sponsors, the lower-division students have ranked highest.

Students are not the only ones who have benefited from the Undergraduate Biology Research Program. According to Sam Ward, who chairs the Department of Molecular and Cellular Biology, faculty members soon began to notice that students in the program were much more knowledgeable in the questions they asked and in the help they gave to others. "It raised the entire level of the discussion," Ward says. Faculty members in turn became more excited about their classes. "It's led to an enormously increased interest in teaching," Ward says.

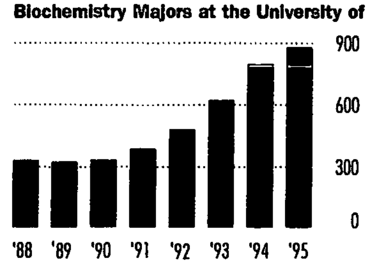
Ward and Wells added to the ferment. They invited outside speakers to talk about teaching and devoted occasional meetings of their journal clubs to articles on pedagogy. They encouraged instructors to put large sections of their courses online at a 60-terminal Biology Learning Center and on a campus network. Exit interviews with graduating seniors allowed instructors to probe the strengths and weaknesses of the educational program. Outreach to surrounding elementary and secondary schools and to two-year colleges brought in students who were eager and ready to do research.

Most important, the two department chairs made teaching an explicit factor in the faculty reward structure. Faculty promotions and raises are now based 40 percent on research (which may include research on teaching), 40 percent on teaching, and 20 percent on service to the university and profession. The teaching of tenured faculty members is evaluated by their peers every two years, nontenured every year. Though all members of their departments are expected to engage in research, Ward and Wells have encouraged some faculty members with special interests in teaching to focus their scholarship on biology education. "We have changed the values of the faculty," says Ward. "We have convinced the faculty to care about teaching."

Enrollment in Introductory Biology Course at the University of Arizona



Number of Molecular and Cellular Biology and Biochemistry Majors at the University of Arizona



The changes have brought an unexpected difficulty. Enrollment in the introductory biology course for life science majors went from 200 in 1985 to 1,700 in 1993, much more than can be attributed to the recent nationwide increase in biology enrollments. At the same time, state budgets have been falling and new

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SELECTED OFFERINGS OF HUMAN BIOLOGY PROGRAM AT STANFORD UNIVERSITY

Human Origins

Contemporary Issues in Human Experimentation

The Human Hand: Evolution, Development, and Molecular Genetics

Multidisciplinary Perspectives on Guilt

Biology and Culture in Language Development

Women, Fertility, and Work: The Biology/Culture Debate About Gender

Ethnogerontology

Biology and Space Exploration

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faculty hires have been limited. "We've created a lot of problems for ourselves," says Wells.

With class levels rising into the hundreds even in upper-level courses, faculty members have been experimenting with ways to handle the added teaching load. Postdocs interested in teaching are now leading some of the discussion sections. Some juniors and seniors are taking a for-credit class on how to tutor lower-division students. A campus-wide electronic bulletin board allows students to initiate and engage in their own discussions on such topics as "Biology and Religion," "Politics and Stuff," and "Books to Read." Annual career days prepare students for an uncertain job market.

"There are ways to change the culture," says Wells, "but it takes time and it can't be dictated. You have to support people who are interested in teaching and not consider them second class citizens."

CREATING A COMMUNITY OF SCHOLARS AT STANFORD UNIVERSITY

An interest in teaching cannot thrive when it remains limited to a few individuals. In successful biology departments the large majority of faculty members are interested in the quality of teaching and strive to improve it. Sustained progress comes from the group, not from heroic loners. Such departments foster a collective concern for teaching, a sense that the department as a whole is responsible for what occurs in classrooms and laboratories.

The biology department and human biology program at Stanford University in California have been particularly successful in building this collective responsibility for teaching. "The question is whether your department values good teaching or not," says biology professor Craig Heller. "People are influenced by the messages they get from the culture."

The human biology program demonstrates many of the emphases in biology education at Stanford. Taught by faculty members from biology, education, anthropology, psychology, and other disciplines, the program focuses on the relationship between human biology and human behavior. It was begun in 1970 by a group of distinguished Stanford faculty members who saw a need for people who could move easily between the worlds of the biological and social sciences. It now graduates between 150 and 170 majors a year, making it about the same size as the more traditional biological sciences major. "Leaders need to understand science, but they also need to understand human behavior," says Heller, a former director of the program.

The structure of the program allows it to draw widely from Stanford's faculty. Carl Djerassi teaches a seminar on birth control; Anne Ehrlich offers a course on environmental policy; Donald Kennedy teaches one called "The Human Predicament."

"One reason why faculty get plugged in to human biology is because they're so excited about the courses they teach," says anthropology professor William Durham, who has been director of the program for the past three years. "We purposefully try to construct the courses around people's interests."

At the same time, the program's leadership works to ensure that faculty enthusiasm is translated into good teaching. Six or seven times a year the faculty members who teach in the program meet to discuss undergraduate teaching. According to Durham, they address such questions as "How do you supervise your teaching assistants?" and "Which activities most engaged your students?" The program also encourages the involvement of faculty members from the medical school and other parts of the Stanford community who do not normally have undergraduate teaching responsibilities. "There are a large number of faculty at Stanford who love to teach undergraduates if given the chance," says Heller.

The biology department at Stanford has adopted many of these same techniques in working with students, nurturing what Heller calls the culture of research. "It is more than just getting them to work in a lab," he says. "It involves influencing how they think, their propensity to question and frame hypotheses, their concern about 'how to know,' which extends even to critical thinking about how to measure things."

Heller has devised a sequence of activities designed to get students to think like scientists.

HHMI investigator Sharon Long at Stanford University discusses genetic crosses with student Eric Engstrom.

First, a seminar course introduces them to the literature and basic questions in a field. Graduate students and postdocs serve as role models and help generate an atmosphere of discussion and inquiry. Next comes an advanced laboratory course emphasizing research methods, with students writing grant proposals that are reviewed by their classmates, just as in a "study section" of a funding agency. Many of the students then submit their research proposals to a university-wide competition for grant support to begin work during the summer on their projects.

The emphasis on students as partners in research has had impressive results. No other major has been as successful in getting undergraduates involved in research. In human biology about half the majors do independent research projects, and the proportion is similar in biology. In any given year well over 100 students in the two programs combined are engaged in original research in the laboratories of Stanford's faculty.

In the past few years faculty members from the biology department, the human biology program, and other science departments have been involved in an effort to extend good science teaching more broadly throughout the student body. A 1995 memorandum from Stanford's provost invited teams of faculty members to design and implement new year-long courses in science, mathematics,

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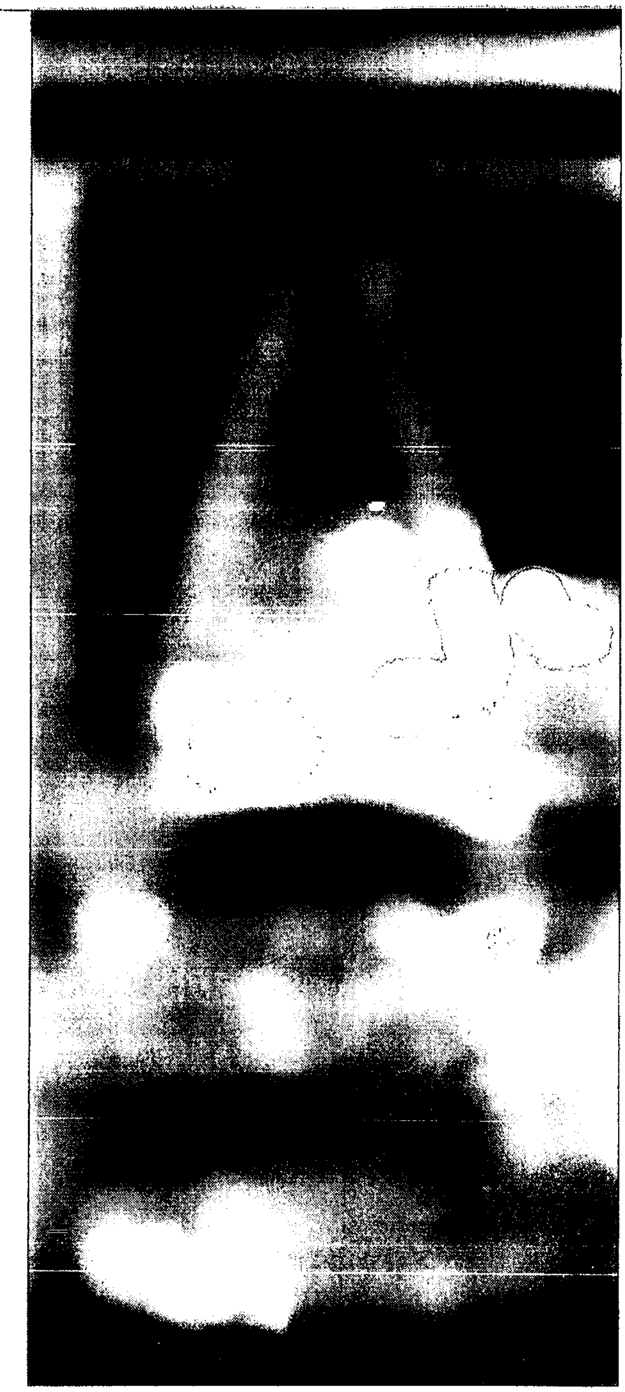
In successful biology departments the large majority of faculty members are interested in the quality of teaching and strive to improve it.

and engineering for students majoring in the humanities and social sciences. All of the courses must include a laboratory component and make significant use of computers. According to the design team for the new track, "the goal is for students to have a serious encounter with the process and essential ideas of mathematics, engineering, and science, with an emphasis on process."

A number of faculty teams have been designing new courses. One team includes a physicist, a mathematician, a neurobiologist, an engineer, and a biochemist who have organized a course that examines "light" from various perspectives. Sharon Long, a professor of biological sciences and HHMI investigator, is among the five organizers, teaching a series of lessons on how light affects biological systems. In one laboratory exercise, students bombard bacteria with ultraviolet radiation. "When the students realize that 90 percent of the cells die within 15 seconds," Long says, "it really changes their mind about getting a suntan."

The new courses seek to equip students with the basic ideas and tools they need to evaluate information and make their own decisions. "All students should know science," says Heller. "There's nothing more critical to our society." Other Stanford faculty members agree that non-majors need more interdisciplinary—and effective—science courses. "I think this is one of the most important missions that university educators have right now," Long says.



REACHING ACROSS GENERATIONS AT MOREHOUSE COLLEGE

The University of Arizona and Stanford University have found that involvement in research as an undergraduate is excellent preparation for many careers. But in some cases, involvement in research has a more focused goal. At Morehouse College, an all-male, historically black college in Atlanta, involvement in research is heavily skewed toward a particular problem—the very low numbers of African Americans among biology faculty members.

Since its founding a few years after the Civil War, Morehouse has sought to instill in young African American men a sense of tradition and responsibility toward future generations. About 5 percent of the country's black Ph.D.s received their undergraduate degrees from Morehouse. Many who have taken academic jobs did so in the hope of encouraging even more young men to enter the professoriate.

"Coming to Morehouse was a seminal event in my life and in choosing a career in science," says Morehouse president Walter Massey, a former director of the National Science Foundation who graduated from Morehouse in 1958 with a combined degree in mathematics and physics. "Several times I

Walter Robinson studied drug resistance as a high school student attending a summer research program at Morehouse College. He is now an undergraduate at Duke University

MISSION STATEMENT OF MOREHOUSE COLLEGE'S BIOLOGY DEPARTMENT

1. To provide students with a fundamental knowledge of biology.

2. To prepare students for and assist them in entering graduate and professional school and the work force.

3. To strengthen students' reading, writing, and quantitative skills.

4. To develop students' analytical reasoning and creative thinking skills.

5. To expose students to contemporary research techniques in biology and to enhance their understanding of the scientific method.

6. To conduct meritorious research in the field of biology.

7. To acquaint students with the history of biology, including the contributions of Black scientists.

8. To engender an appreciation among students of the social and economic implications of discoveries in biology.

9. To make students aware of ethical and moral issues related to basic tenets in biology.

thought I couldn't complete the degree. But my mentors had confidence in me even when I didn't have confidence in myself."

In the late 1980s, Morehouse's biology department began a fundamental restructuring of its curriculum. Guided by a newly adopted mission statement, the department developed a new set of investigative labs, revamped several courses, and hired new faculty members to teach them.

One of the new hires was Joseph McCray, who had been working in Austria for the previous ten years with Sandoz Pharmaceuticals. McCray, who is one of three Morehouse alumni in the eight-member biology department, took the job because of what he calls "the catalytic effect" that producing African American professors has on attracting more African Americans into science.

"My hidden agenda—or maybe not so hidden—is to seed the leading biomedical research centers in the country with Morehouse students, and we're getting there," McCray says. So far, his students have gone to Syracuse, Yale, the University of California–San Francisco, and Johns Hopkins. "My second hidden agenda," he adds, "is for one of them to win a Nobel prize."

As at other institutions, there is a tension at Morehouse between producing students who go on to medical school or to graduate school. Out of Morehouse's 50 to 60 biology majors each year, about half go to medical or dental school. "For nine out of ten students, the only role models that they've seen have been professional people—doctors, dentists," says professor David Cooke III. "By the time they get to Morehouse they've already made up their minds. But sometimes minds can be changed."

Senior Raymond Swanson is one student whose mind has changed—at least partly. "When you get here, medical school is all you know about," he says. "But then you start to see other things." For two summers he did research projects at the University of California–San Francisco. Now he's thinking about combining a Ph.D. with a dentistry degree.

"On average, about three graduates of the biology department attend graduate school every year," says J. K. Haynes, who chairs the department. "If we could increase that number to five to ten, we would be sending more black men to graduate programs in biology than any other college in the country. We would be making a major contribution."

The best way to do that, according to Haynes, would be to recruit more intensively at the high school level. Through its Summer Science Institute, Morehouse brings about 100 students to campus every summer to study science and carry out research. Haynes would like to do even more to attract promising young African American men to Morehouse's biology program. "If we could recruit 10 to 15 bright freshmen who were interested in research, we have in place the support mechanisms to keep them on track to graduate schools," he says.

Haynes knows the department needs to offer top students the resources that other colleges and universities have. And Morehouse, like other small liberal arts colleges, has been feeling the pinch of tight research funding. To make up for the shortfall, Haynes and Massey hope to raise a $1 million research endowment for the sciences from private donations. Returns from the endowment would help support faculty members between grants and provide some startup funding. In that way Morehouse could keep alive the research projects that interest undergraduates in scholarship and in academic careers of their own. "I would like to see every Morehouse student engaged in research," says Massey.

THE BOTTOM LINE

The biology programs at Stanford, Morehouse, and Arizona have different students, courses, personalities, and traditions. Yet all three consistently produce students who are enthusiastic about biology and faculty members who are enthusiastic about teaching. What are they doing right?

First, all three demonstrate that *the best kind of teaching is one-on-one teaching*. The personal bonds forged in a seminar room, amidst the clutter of a laboratory bench, or at a Friday afternoon gathering cannot be replaced. As many biologists have attested, an interest in science often is sparked not only by the fascination of the subject matter but also by a particular individual—a research mentor or teacher who guides young people in their careers. At Morehouse, the current faculty members emulate their own mentors even as they act as mentors to new generations of students.

Providing this kind of personal attention for all students can be difficult where already large enrollments are increasing. Nevertheless, many science departments—recognizing the crucial role that mentoring plays in a young scientist's development—are structuring their offerings to maximize personal interactions between faculty members and students.

Second, successful undergraduate biology programs demonstrate that *change must be firmly grounded at the departmental or programmatic level*. As the University of Arizona has demonstrated, good ideas can come from many sources. But to have a lasting effect, those ideas have to be modified, adapted, and embraced until they become part of the local culture. The process requires

"If the faculty is not committed to research, if it's not a part of their life, the chances of communicating that interest to students in an effective way are minuscule."

—Stephen Arch, Reed College

"We wouldn't consider ourselves good scientists if we didn't keep up with what's going on in science. The same should be true when it comes to education."

—Sondra Lazarowitz, University of Illinois at Urbana-Champaign

"We don't share enough of what we do in our teaching. We need to discuss teaching and learning and share in the same ways that we share our scientific scholarship. Each of us shouldn't have to reinvent the wheel."

—Jay Labov, Colby College

"The most important question we have to consider as a nation is why undergraduate students do not consider mathematics and science an essential part of their culture and their lives."

–Sheila Tobias, author

"There's a mood in this state, and a mood in the country, that is not pro-education, and certainly not pro-education for the people who can least afford it."

—Sharon Cosloy, City College of New York

"There's no way you can cover all of biology, or any other field. So the important thing is to teach the skills and thinking processes that enable students to acquire and synthesize information."

—Jo Handelsman, University of Wisconsin–Madison

leadership and perseverance. It usually involves changes in attitudes, perceptions, and goals. In that respect, effective department heads often are those who can instill positive attitudes without being autocratic. Administrators, too, can influence the culture that surrounds teaching through funds for travel or curriculum development, new faculty positions, and a willingness to support changes in the reward structure.

Third, *educational improvements generally require continuous and incremental change.* A commitment to good teaching implies a constant willingness to look for what works and what does not work. New curricula and teaching techniques may be important, but the most critical factor is a steadfast desire to build on teaching techniques and experiences that are successful. The human biology program at Stanford is now over 25 years old, but its leaders have not lost sight of the need for continual improvements in teaching.

"Are we catering too much to the MTV generation, to the kids who were brought up with 30-second sound bites? We have to be careful not to lose our commitment to our core values."

—Susan Henry, Carnegie Mellon University

"Even in advanced courses, students haven't been taught to think. Now we're getting accused of changing the rules. But you get past that. And sometimes, long after a course is over, you hear back from a student that that course was the best they ever took."

—Paul Williams, University of Wisconsin–Madison

"Universities don't like to think about productivity gains. That means you have to get rid of people. But we've done health care. We've done corporate America. Guess who's next?

—Orville Chapman, UCLA

"At 2:30 in the morning we had 217 students who were on our network. When you have an eighth of your student body on the network at 2:30 in the morning, there's teaching and learning going on, and the faculty don't have to be physically present."

—Martha Crunkleton, Bates College

Finally, *good teaching is infectious.* It may be true that good research is recognized globally and good teaching is recognized locally, but local rewards can be immediate and personal. Many faculty members chose to enter academia because they were interested in teaching. When they find themselves part of a community of scholars committed to teaching, that interest can flourish. Departments and institutions must be structured in such a way as to allow such communities to grow and prosper.

Above all, good teaching highlights the underlying connections between the creation and dissemination of knowledge. Here, in the fundamental objectives of higher education, is where students and faculty members derive their richest rewards. "We get excited about doing biology because it's fun," says Stanford's Heller. "And people who are excited about biology like to convey their enthusiasm."

"One consequence of having undergraduates in laboratories is that you get immediate feedback on a course. If you've just given a crummy lecture, you're probably going to hear about it."

—Sam Ward, University of Arizona

"I ask my students, 'What's the difference between an undergraduate and a graduate student?' And I tell them that the answer is three months."

—Joseph McCray, Morehouse College

HOWARD HUGHES MEDICAL INSTITUTE

Double immunofluorescence of cultured human skin cells illustrates how genetically modified keratin interacts with the body's own keratin network.

BEYOND BIO 101:
THE TRANSFORMATION OF UNDERGRADUATE BIOLOGY EDUCATION

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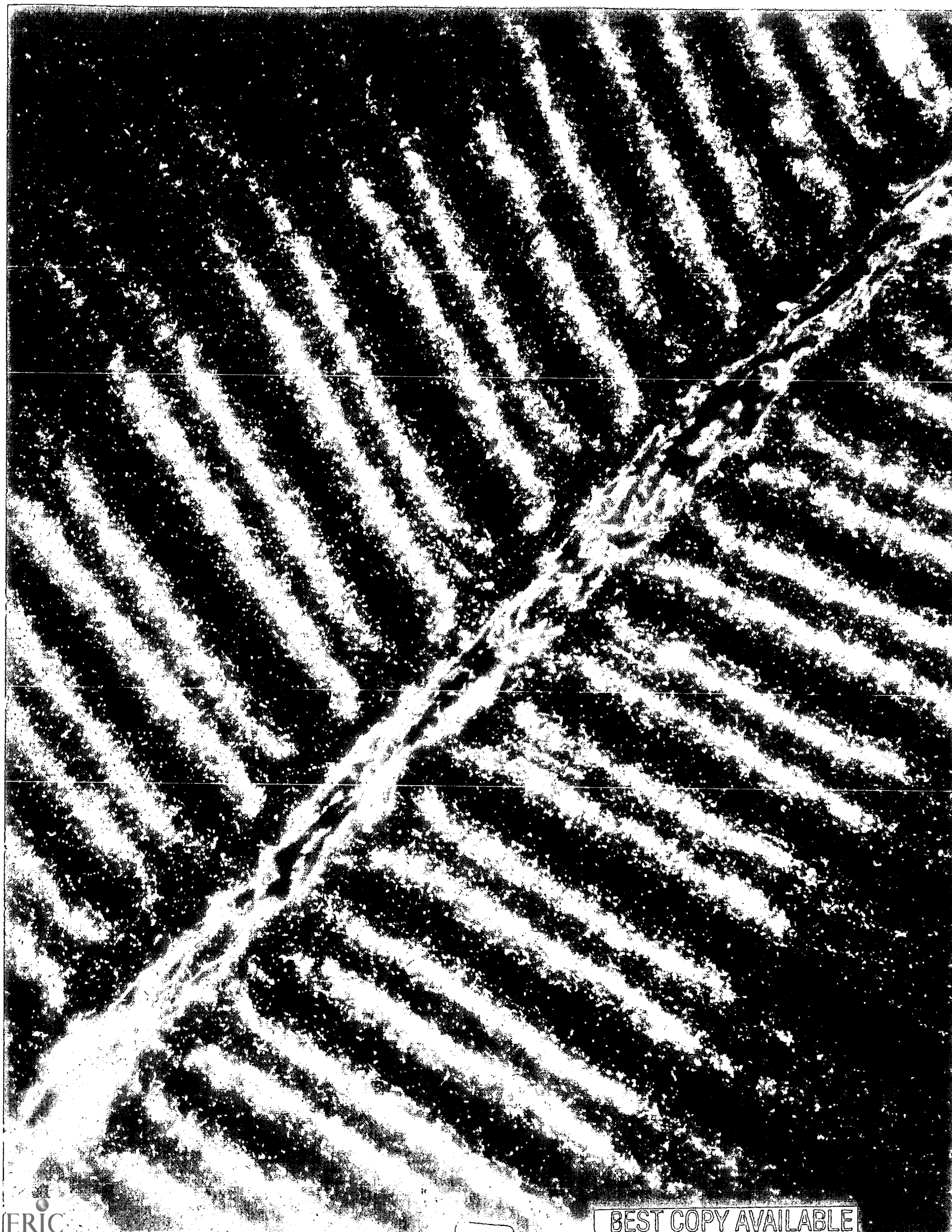

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