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ABSTRACT

This meeting proceedings provide a forum for the program directors to discuss various educational challenges facing undergraduate science departments and to learn how their colleagues in other institutions are addressing the same challenges. The meeting theme was New Tools for Science Education and participants examined issues related to how new educational technologies are transforming teaching and learning in undergraduate science education and in outreach to elementary and secondary schools. Appendices contain a list of meeting attendees, and undergraduate biological sciences education program award recipients from 1988-1994. (DDR)

Howard Hughes Medical Institute

New Tools for Science Education

Undergraduate Program Directors Meeting

October 25–27, 1995

Undergraduate Biological Sciences Education Program

Office of Grants and Special Programs

New Tools for Science Education

Perspectives on How New Technologies Are Transforming Undergraduate Science Education and Outreach to Elementary and Secondary Schools

Undergraduate Program
Directors Meeting

October 25–27, 1995

Undergraduate Biological Sciences Education Program

Office of Grants and Special Programs

About This Report

In the fall of each year, the Howard Hughes Medical Institute convenes a meeting of directors of the programs supported by grants from the Institute's Undergraduate Biological Sciences Education Program. The meetings provide a forum for the program directors to discuss various educational challenges facing undergraduate science departments, and to learn how their colleagues in other institutions and other members of the science education community are addressing those challenges.

Each meeting is organized around a central theme, with plenary panel discussions and workshop demonstrations and discussions devoted to topics within that theme. The focus of the 1995 meeting is New Tools for Science Education. The program directors examined issues related to how new educational technologies are transforming learning and teaching in undergraduate science education and in outreach to elementary and secondary schools. Past meeting themes have included Science Education: Expanding the Role of Science Departments *(1994)*; Institutional Strategies for Enhancing Undergraduate Science Education *(1993)*; Enriching the Undergraduate Laboratory Experience *(1992)*; *and* Attracting Students to Science: Undergraduate and Precollege Programs *(1991)*.

This report contains the proceedings of the 1995 meeting.

The contributions of Bill Carrigan, Judith Dickson, Eleanor Mayfield, Jeff Porro, Frank Portugal, Ph.D., and Jane Stevens to this report are gratefully acknowledged.
The photographs were taken by William K. Geiger.

The names of colleges and universities are listed as they appear in the 1996 *Higher Education Directory*.

Contents

The Howard Hughes Medical Institute was founded in 1953 by aviator-industrialist Howard R. Hughes. Its charter, in part, reads:

The primary purpose and objective of the Howard Hughes Medical Institute shall be the promotion of human knowledge within the field of the basic sciences (principally the field of medical research and medical education) and the effective application thereof for the benefit of mankind.

Biomedical Research Program

The Howard Hughes Medical Institute is a nonprofit medical research organization dedicated to basic biomedical research and education. Its principal objectives are the advancement of fundamental knowledge in biomedical science and the application of new scientific knowledge to the alleviation of disease and the promotion of health. Through its program of direct conduct of medical research in conjunction with hospitals, it employs over 270 independent investigators at its laboratories in more than 60 leading academic medical centers, universities, and hospitals throughout the United States. The Institute conducts research in five broad areas: cell biology, genetics, immunology, neuroscience, and structural biology.

To aid these research efforts, the Institute is involved in the training of graduate and postgraduate students in its investigators' laboratories, has given substantial support to the international genome mapping program, provides research training to medical students through the Research Scholars Program (conducted jointly with the National Institutes of Health), and organizes scientific conferences, workshops, and program reviews.

Grants and Special Programs

To complement its research program, the Institute has a grants program dedicated to strengthening education in the biological and related sciences. Administered by the Office of Grants and Special Programs, the Institute grants are designed to enhance science education at the graduate, undergraduate, and precollege levels; to increase public understanding and appreciation of science; and to support fundamental biomedical research abroad. In addition, a comprehensive assessment effort is under way. The grants reach a wide range of institutions involved in formal and informal science education, including colleges and universities, medical schools, research institutes, elementary and secondary schools, and museums.

Since 1988 the Institute's grants program has provided about $80 million in fellowship support to 1,200 students and physician scientists who have shown strong promise of becoming tomorrow's leading biomedical researchers.

The undergraduate program has awarded $290 million to strengthen life sciences education at 213 public and private colleges and universities. These awards are intended to enrich educational opportunities for science majors and enhance the general scientific literacy of students who major in nonscience subjects.

In addition to precollege activities in the undergraduate program, the Institute has awarded $11 million to 51 museums, aquaria, botanical gardens, and zoos to support innovative education programs and to interest youngsters in science. In 1994 the precollege program was extended by awards totaling $10 million to 42 biomedical research institutions.

The Institute's local science education initiatives provide opportunities in the Washington, D.C., area for precollege students at all levels to gain experience in the science classroom and laboratory. A holiday lecture series on science for high school students, held each December, is telecast via satellite throughout North America to more than 8,000 junior and senior high schools.

A research resources competition for U.S. medical schools was held in 1995. A total of $80 million in awards to 30 U.S. medical schools was held in 1995. Annual payments of $0.55–$1 million will be made over four years for new faculty start-up, core facilities, pilot projects, emergency funds, and other activities that will help the schools sustain their commitment to research. The research resources program also provides support to research organizations serving the biomedical community as unique resource laboratories and teaching facilities.

Through a grants initiative launched in 1991, the Institute supports the research of outstanding biomedical scientists abroad. Altogether, more than $38 million in five-year grants has been awarded to 143 international research scholars.

The Institute has a home page on the World Wide Web, with direct links to the grant sites. The universal resource locator (URL) is <http://www.hhmi.org>.

Undergraduate Biological Sciences Education Program

The purpose of this program is to strengthen the national quality of college-level education in the biological sciences and other scientific disciplines as they relate to biology. Another important objective is to support outstanding programs that seek to attract and retain students in scientific fields, including women and members of minority groups underrepresented in the sciences.

Colleges and universities are invited to compete for undergraduate grants on the basis of their recent records of having graduated students who went on to matriculate in medical school or to earn a Ph.D. in biology, chemistry, physics, or mathematics.

The Institute encourages institutions to develop programs that respond to their particular strengths and needs. In the current program phase, grants are awarded in support of student research and broadening access programs; equipment and laboratory development; and outreach programs linking science departments with community colleges, elementary and secondary schools, and other institutions.

In the area of student re-search and broadening access, the Institute enables students to engage in summer and academic-year laboratory experiences on and off campus. It supports prefreshman bridging programs, laboratory training, opportunities for students to present their research at scientific meetings, and other activities that promote a culture of science at the undergraduate level. It supports efforts to enhance education in biology, integrate it with other disciplines, and modernize teaching laboratories through renovation and equipment acquisition. Science outreach programs for faculty members, teachers, and students at community colleges and secondary and elementary schools are also supported.

The Institute has awarded approximately $290 million in undergraduate science education grants to 213 public and private colleges and universities in six rounds of competition. In 1988, 34 liberal arts and comprehensive colleges and 10 historically black institutions were awarded $30.4 million for their science programs. In 1989–1990, 51 research and doctorate-granting universities received $61 million to enhance undergraduate science education. In the third round, completed in 1991, 44 additional liberal arts, comprehensive, and minority institutions were awarded $31.5 million in grant support. In 1992–1993, 42 additional research and doctorate-granting universities were awarded $52.4 million. In the fifth competition, completed in 1993, a total of 47 liberal arts, comprehensive, and minority institutions received $28.5 million. In a sixth competition, held in 1994, 62 research and doctorate-granting universities were awarded four-year grants totaling $86 million.

Preface

Purnell W. Choppin, M.D. □ President

In February of this year, the Howard Hughes Medical Institute introduced its World Wide Web home page, filled with information for Internet users about HHMI-supported advances in biomedical research, science education programs, opportunities they provide, and related topics.

The site includes "Where in the World Is HHMI?" This offers maps that give detailed information about the location of HHMI programs, including links to many of the home pages of HHMI scientists and grantees. Visitors to this feature have many choices to explore, with 280 investigators at more than 60 sites, nearly 350 grantee institutions (medical schools, research institutes, colleges and universities, science museums, etc.), 700 current fellows, and 143 International Research Scholars.

Like many other organizations concerned with research and science education, the Institute realizes the value of making this information available on the Internet. Communication and information is the lifeblood of science, an increasingly global enterprise. But new information technology is making the globe smaller; geneticists from Paris and Princeton, for example, now collaborate in charting the human genome; structural biologists and educators, aided by a vast database, share protein structures on-line; and scientists worldwide exchange data and information via the Internet and e-mail.

This type of innovative exchange will surely serve science in new and yet unimagined ways. It has invigorated science education, where school teachers and college faculty are developing multimedia curricula, posting messages in newsgroups, and sharing educational modules.

Since 1988 HHMI has awarded through its grants program more than $518 million to enhance science education spanning the United States, from Maine to Hawaii. These funds are spent at educational levels from prekindergarten to postdoctoral. Some of the most exciting uses of Institute funds have been the development of educational technologies for undergraduate science education. These include interactive computer-guided examination of biological processes, electronic texts, and computer tools for visualizing complex biological and chemical structures.

These educational tools cannot wholly replace the experience of the "wet lab," where science students are exposed to the challenges, unpredictable nature, and fiber of the real world. They have proved valuable, however, in allowing students to prepare themselves at their own pace for the actual laboratory experience. Using pow-

Dr. Purnell Choppin, President of HHMI, and Dr. Harvey Lodish of the Whitehead Institute of Biomedical Research at the Massachusetts Institute of Technology meet before Dr. Lodish's keynote remarks on the role of technology in undergraduate teaching and research.

erful simulations, they also afford a better grasp of the concepts that have traditionally been presented in text or two-dimensional figures.

For example, a computer program designed to teach biochemistry at the University of California–San Diego provides multimedia modules that help students prepare for laboratories and enhance their understanding of the interrelationships between concepts and tools of chemistry, mathematics, biology, and physics. At Vanderbilt University a computer-networked wet lab is used by the molecular biology department to enable students to capture and record images through tutorials, simulations, and data analysis. Complex scientific concepts are relayed to students' computer screens as they work at the bench. Computers can help students with a crucial step in learning and doing science—critical thinking. For example, prospective histologists, through computer simulation and modeling, can augment their experience by learning how various cells interact and function.

Today's students are learning to use the newest tools of science, where computers serve in analyzing such phenomena as protein folding, seismic activity, and oceanographic and atmospheric conditions. The biological sciences have undergone a revolution in the past 25 years. New investigative technology has enabled researchers to make astounding discoveries at the cellular, molecular, and atomic levels. Ever faster and more powerful computers perform the prodigious computations needed to visualize the interactions taking place as well as to model those that might occur.

Despite our enthusiasm for these new approaches to science education, we are aware that, as new tools, their proper use must yet be learned. This challenges faculty to rethink their roles in the face of such rapidly advancing technology. Educators will not be replaced by computers. They will always have the essential role of instilling in young minds the disciplines of rigorous thinking, originality, and versatility. But students who are educated with the aid of new educational technologies may later, as scientists, bring to research and education resourcefulness and flexibility yet unimagined.

Despite all the hype about educational technology, we are still aware of talking about the "promise" of technology, versus citing tangible evidence of greater productivity, broader access, or higher-quality education. Any gains to be had from the use of educational technologies will ultimately lie in the value of the teaching methods they support. Recognizing this, the Institute recently awarded an $800,000 grant to the National Research Council/ National Academy of Sciences to undertake a national review of science education technology, including quality control in educational software, and a review of software by scientific disciplines.

The HHMI community of scientists and educators continues to grow. A large number of the Institute's grantee colleges, universities, medical schools, museums, and other institutions have created home pages—graphical, linked sites on the World Wide Web—for a wide range of educational and administrative purposes. Through the HHMI home page, one can now visit the Grants for Science Education Virtual Campus to learn about Institute-supported initiatives. It is both a marvel and a joy to visualize this international community on-line. Visit us on the Web and let us know what you think. URL: <http://www.hhmi.org>

Introduction: Powerful New Tools for Learning Science

Joseph G. Perpich, M.D., J.D. ☐ Vice President for Grants and Special Programs

Science fiction has for many years shown us a future where computers have the power to control, command, improve, or corrupt the human race. Consider the novel and film *2001: A Space Odyssey*. The Frankenstein-like vision of machines determining our fate—the potential destruction of the creator by the created—is beguiling as fantasy. This view, however, grows increasingly unreal in today's world, where millions of American homes have a personal computer, half of all public schools are linked to the Internet,[1] and over half of all college students have access to the Internet and the World Wide Web.[2]

In 1993 more than two-thirds of all students in grades 1 through 12 used a computer at home or at school. And according to a 1995 survey of computers in higher education, the percentage of college courses using e-mail and multimedia resources more than doubled in 1995, while the use of computer simulations and commercial courseware increased by more than 50 percent.[3]

The landmark chess match of 1996 between champion Gary Kasparov and IBM's supercomputer Deep Blue further illustrates the evolution of the information age, where man "bytes" machine. A cartoonist recently captured the essence of this contest. Kasparov and Deep Blue are at the chess board, and a balloon over Kasparov's head reads "I think, therefore you are."

No longer are new information technologies perceived as unconstrained and self-reliant, but rather as powerful tools that can change the way we communicate, learn, analyze, and plan. Technology has finally been placed in the hands of the citizenry, making it more democratic and less feared. It is perhaps the youngest among us who are the most comfortable with these new powers. Our children are teaching us how to travel the information highway. They have come to expect and welcome the use of computers in all aspects of their lives, but most particularly in the classroom.

No longer are new information technologies perceived as unconstrained and self-reliant, but rather as powerful tools that can change the way we communicate, learn, analyze, and plan

We are clearly at the edge of a new frontier. Computer and communications technologies are rapidly breaking down the constraints of time and distance and fundamentally transforming our economy and society. The forces unleashed by the information revolution are sweeping over higher education, just as they are now surging through govern-

1 Riley, Richard, U.S. Secretary of Education, citing *National Center for Education Statistics*. The Associated Press, February 16, 1996.

2 Green, Kenneth C. The 1995 National Survey of Desktop Computing in Higher Education. Encino, California: The Campus Computing Project (newsletter), January 1996.

3 Ibid.

We must be wary of . . . the widening gap between those who are being prepared for lives and careers in the information age and those who may find themselves increasingly behind.

ment, the corporate world, and our health care system.

A report from the Pew Higher Education Roundtable puts matters succinctly: "What telemarketing and phone banks did for catalog sales, what QVC did for home shopping, what ATMs did for banking, the information highway is about to do for distance learning and higher education."[4] The coming transformation has the potential to reinvigorate university classrooms, strengthen teachers, give a much wider segment of our population a fair chance for higher learning, and empower students.

Despite these strong promises, however, we must be wary of what has been called the "digital divide," the widening gap between those who are being prepared for lives and careers in the information age and those who may find themselves increasingly behind. Many classrooms have no space for equipment and were not built to accommodate keyboards, monitors, and modems. Anecdotes abound about modem-equipped computers sitting idle in classrooms that have no telephone outlet. User-support issues present a major financial and technological challenge for institutions at all educational levels.

And we cannot assume that more computers in our schools and institutions of higher education translates into more learning. We still have a long way to go in developing appropriate educational software, training teachers and faculty in use of information technologies for curriculum development and implementation, and evaluating the impact of educational technologies on learning. The Institute's award to the National Research Council to review science education technology will elicit timely advice in this critical area.

[4] The Pew Higher Education Roundtable. *Policy Perspectives* 5:3A, April 1994.

Teaching, Research, and Technological Innovation: a Convergent Path

At the undergraduate program directors meeting held in Chevy Chase, October 26–28, 1995, more than 100 directors of Institute-funded programs met with resource people from government and industry to discuss the significance of computer-based technology in undergraduate science education.

The convergence of changing technological approaches to biological research and the development of new educational technologies has not gone unnoticed by those who both teach and conduct research. In the words of keynote speaker Harvey Lodish, Professor of Biology at the Massachusetts Institute of Technology, "Biology has evolved. Unlike math and physics, biology is not built on theorems. It is now an analytical science. A good way to learn bi-

Educational technologies lend themselves to new approaches to teaching science by bringing the process of scientific discovery to students first-hand in a visual, student-centered manner that more closely parallels the scientific process.

Drs. Susan Henry, Carnegie Mellon University, Joseph G. Perpich, HHMI Vice President for Grants and Special Programs, and Harvey Lodish discuss how educational technology is changing the way science is taught at the undergraduate level.

ology is to solve problems. In addition, students must learn the 'why' behind the 'how.'" Educational technologies lend themselves to new approaches to teaching science by bringing the process of scientific discovery to students firsthand in a visual, student-centered manner that more closely parallels the scientific process.

Although the use of new information technologies in science education is still in the developmental stage, the approaches presented at the meeting were many and varied. Program directors reported attempts to fulfill the dual roles of the university—teaching and research—by providing an educational experience that not only instructs but also prepares the young mind for independent exploration with the aid of powerful tools and databases. In the sciences, reported Kent Wilson, a chemistry professor at the University of California–San Diego, "computers are especially generous in their ability to provide students with a view of a dynamic, three-dimensional world that cannot be sufficiently well represented through the confines of a textbook, blackboard, or overhead projector."[5]

Seeing Is Believing

Trying to imagine what educational technology can do to help teach science is almost as exciting as actually seeing it at work. Students are designing molecules and calculating their properties in the laboratory; putting on a virtual reality helmet to knock atoms off a silicon wafer

A well-designed system can enable a motivated student to simulate a month of laboratory experiments in an afternoon. It allows for self-discovery of the principles that underlie the system's behavior—and, at the same time, exposes students to how scientists think.

5 Illman, Deborah L. Multimedia tools gain favor for chemistry presentations. *Chemical & Engineering News*, May 9, 1994.

projected by a scanning tunneling microscope; setting up the Wilson telescope via the Internet and downloading data the next day; and visualizing proteins across a series of mammalian species to explore concepts in evolutionary biology.

These approaches, say the undergraduate science program directors, achieve several important goals. They motivate the students in ways conventional methods cannot; they allow students to do things electronically that they can't do in the laboratory because of the constraints of time and resources; and perhaps most important, they help students become responsible for their own learning.

Presentations made during these proceedings demonstrated the capacity of computers to offer fast interactivity and realistic simulations in the educational setting. Even the best textbooks are fundamentally inert. Their information flows one way, and they cannot respond to a student's questions or mistakes. The nearest most texts come to interactivity is supplying the answers at the back of the book. But computers can demand responses and allow a student to chart an individual path of discovery through a maze of information. A well-designed system can enable a motivated student to simulate a month of laboratory experiments in an afternoon. It allows for self-discovery of the principles that underlie the system's behavior—and, at the same time, exposes students to how scientists think.

In his keynote address, Dr. Lodish presented an example of an interactive, multimedia approach to helping undergraduate students understand the value of various experimental organisms. His curriculum responds to frequent student questions about why bacteria are used for basic studies of DNA and gene function, or why yeast is studied as a versatile life form, or why mice are manipulated genetically in approaches to human biology. These topics are published as interactive video CD-ROMs, and the potential for integration and cross referencing is enormous. Marvin Minsky of MIT once remarked, "Can you imagine that they used to have libraries where the books didn't talk to one another?"[6]

The range of activities that participants reported on at the meeting was stunning. The projects can be broadly categorized into presentation of information, communication, or simulation.

In presentation, Gabriele Wienhausen demonstrated the latest version of a computerized laboratory manual for introductory biology under development at the University of California–San Diego. Steve Heidemann of Michigan State University showed off a set of computer-

[6] Wulf, William A. Warning: information technology will transform the university. *Issues in Science and Technology*, Summer 1995.

ized animations of basic molecular biological processes.

As examples of communication projects, Peter Bruns described Cornell University's network for biology teachers, and Martha Crunkelton discussed how biology students at Bates keep the college's local network buzzing through the night.

For simulation, Hillel Chiel of Case Western Reserve University demonstrated his set of programs on neurophysiological principles, and Beloit's John Jungck showed a suite of molecular biological simulators that allow students to manipulate—virtually—the basic tools of recombinant DNA technology. This curriculum, BioQUEST, is developed through a collaborative and peer-reviewed process among faculty at numerous colleges and universities.

Anything that impels students to think critically to solve a problem is a powerful educational device. Blended together, the communications, multimedia, and interactive capabilities conferred by the new technology offer great potential for transforming education. The problem, however, is that acquiring the hardware, creating the software, and changing institutional habits to allow full exploitation of this potential all consume much money and time. In addition, the technology is so new that no one is yet sure what works and what doesn't, or how to measure its impact.

New Roles for Faculty

Society will always need people who can think logically, argue coherently, see clearly, and make new discoveries. No technology will change the fundamental fact that children are not born with these skills. People must learn to think, and teachers will always have a key role in guiding students through learning. No computer, by itself, will ever inspire a student to strive for excellence, but students will always have to be inspired.

Educators have a lot to learn as the new wave of educational technology breaks. The computer may be the first fundamentally new tool for teaching since the textbook, and educators are still feeling their way. No one really knows yet how to exploit fully the powers of this new multimedium; faculty must still learn to play the new instrument that technology has thrust into their hands. The basic challenge facing college professors today is to integrate the new world of simulation and interactive technologies with their own unique role as mentor, coach, facilitator, and teacher. In the words of John Jungck, educational technology can redefine the teacher's role as the "guide on the side," rather than the "sage on the stage."

Not everyone is convinced, of course, that the technology can replace the classroom teacher or revitalize education. Clifford Stoll, in his 1995 book *Silicon*

The basic challenge facing college professors today is to integrate the new world of simulation and interactive technologies with their own unique role as mentor, coach, facilitator, and teacher.

The higher education setting provides a place for interaction, discussion, introspection, and growth. These are the attributes that help students to distinguish between information and data, and to develop the research skills they will need to understand science.

Snake Oil,[7] warns against society placing too much hope in technology. While raising some interesting points about the role of digital technology in education, he stresses the importance of having good teachers who can convey method as well as content. He fears that the computer is a barrier to close teaching relationships and concludes that interactive videos and remote broadcasts are no substitute for studying under a fired-up teacher who is there in person.

Orville Chapman of the University of California–Los Angeles counters, "University faculty won't be replaced by computers; they will be replaced by people who use computers." But professors can replace themselves—if they are willing and able to adapt. Whatever changes occur, it is safe to say that no successful university professor of the next century will merely stand before a lecture hall writing notes on a blackboard for students to copy. No teacher who expects students' respect and attention will shun e-mail. No productive mentor will ignore the vast information resources of the Internet.

Developing computer-based instructional materials requires science faculty to think differently about what and how they are teaching, especially if they are replacing a traditional classroom environment with project-oriented learning. This is why some have reported that using educational technology actually improves their teaching skills. Because it can take months or years to develop a successful computer program, most program directors believe that academic scientists should be released from some of their normal duties while working on the programs. Many said that successful computer programs should be regarded as published research and rewarded in considerations of tenure and promotion. At the University of Miami, for example, release time and payments of summer salary are incentives used to involve faculty in training and developing computer-based instruction.

Chapman describes four levels of faculty acceptance of technology. The first is outright denial. The second is the decision to use the technology in a lecture as a means of visualizing, like a high-tech slideshow. The third is encouragement of the use of interactive technology by students outside the classroom. The fourth, and most exciting stage, is the use of technology to enable students to do things they have never done before.

And just as the insight and wisdom of a teacher or mentor cannot be replaced with a computer, the college or university environment cannot be replaced with a local area network. The

7 Stoll, Clifford. *Silicon Snake Oil: Second Thoughts on the Information Highway*. New York, Doubleday, 1995.

higher education setting provides a place for interaction, discussion, introspection, and growth. These are the attributes that help students to distinguish between information and data, and to develop the research skills they will need to understand science.

Electronic communication, however, can vastly expand and augment the learning environment of the college campus. For example, Peter Bruns of Cornell University told conference participants about CIBTnet, the Cornell Institute for Biology Teachers Network. Cornell University sponsors a three-week summer program for high school biology teachers. At the end of its seventh annual session, participants are sent home with a modem-equipped computer and telecommunications software. The teachers become instant members of the CBITnet.

Bruns believes that CIBTnet has worked well (4,505 hours logged in four years) because the people who use it know one another and have met face-to-face. They first meet at the summer program and get together with other program alumni twice a year for one-day seminars. Communications networks, whether electronic or human, are most powerful when there is a community of users behind them who share a common interest or goal.

Facing the Natural World

A reasonable question to ask of those who are developing virtual and on-line lectures and laboratories is whether they can or should completely replace the traditional "wet lab," where students use glassware, scientific equipment, reagents, and experimental designs to learn techniques and record data.

Nearly all in attendance at this meeting of program directors agreed that these experiences cannot be replaced, but only made better by simulations. For example, at Wellesley College, students first do hands-on experiments and then use computer simulations to model situations that couldn't be performed in the laboratory, either because of constraints of time, equipment, or complexity. At the University of California–San Diego, the approach is at the front end. Students first "walk through" an experiment on an interactive lab module and then move next door into the wet lab to actually conduct the experiment.

Martha Crunkleton of Bates College suggests that visually oriented students are positioned to make the most of computer-based technology. For some, three-dimensional visuals are highly effective. Subjects such as plate tectonics are more effectively presented on computers than on a blackboard. In neurobiology, the effects of different neuropathways on neu-

An interactive CD-ROM can tell you how to build a cabinet; virtual reality can let you look inside it; but you don't really get a sense of the whole experience until you take up the tools and actually start to work.

The truth is we don't yet know how effective these tools will be. We need to assess them as we do all other educational approaches, and this will likely require new avenues to assessment.

ronal excitability can better be demonstrated than described.

Computers can also instruct in the use of laboratory instrumentation, enhancing understanding of electron microscopy, flow cytometry, PCR, atomic emission spectrometry, and hydrology. Often students will get hung up in a laboratory, struggling with equipment and technique and missing the principles behind the exercise. Simulations can get them past those critical points so that they enter the laboratory ready to learn.

Hillel Chiel offered the useful analogy of a cabinet maker, comparing laboratory science to learning a craft. An interactive CD-ROM can tell you how to build a cabinet; virtual reality can let you look inside it; but you don't really get a sense of the whole experience until you take up the tools and actually start to work. Students will always need experiences in the world of live organisms, which are variable and sometimes unpredictable. They also need the experience of failure, which might not occur on-line but often occurs in research.

Technology, some believe, should not replace components of more traditional educational environments in which students learn crucial skills, such as careful record-keeping and clear writing. Although picturesque simulations can make learning more exciting, some faculty are concerned that educational technology is appealing too much to the TV generation and will shortchange students in skills they will need for the often laborious enterprise of science.

Is Less More?

Someone once said that when you don't know where you're going, any road will take you there. So where are we going on this stretch of the information highway? How do we know that educational technology will improve learning, or advance comprehension and enthusiasm for science, or assist faculty?

Some educators think that multimedia approaches to science education run the risk of covering less content because they tend to focus on project-oriented curricula at the expense of critical thinking. This concern has led others to counter that less is more. Students enrolled in innovative programs develop a depth and retention of knowledge that is unmatched in the traditional approach to science education. Still others argue that less is only more if it provides students with concepts they need in dealing with the world around them.

The truth is we don't yet know how effective these tools will be. We need to assess them as we do all other educational approaches, and this will likely require new avenues to assessment. Do students finish science courses and go on to take others, or develop more positive attitudes about science? Does the technology change the way people understand science? Does it provide access to science learning that would not otherwise have occurred? More basically, do students like computer presentations of materials?

Setting a Deliberate and Thoughtful Course

The Institute is optimistic about the future of educational technology in science education at all levels. Our enthusiasm is shared. It was clear from the meeting discussions that people are hungry for opportunities to share information and form new collaborative relationships, to trade their ideas and experiences with others. The two most frequently asked questions at this meeting were surely What's your e-mail address? and Is that available on the Web?

It was also clear, however, that commercialization and profit—two prime movers in our capitalist economy—will be important catalysts for the creation of educational technology. The investment required to create a good teaching tool is enormous, and people need returns on investment, whether financial or philosophical. When asked how much work had gone into her beautifully crafted interactive laboratory manual, Gabriele Wienhausen smiled wistfully and said, "It's taken more time than we would ever have believed possible, and we're still not done." Harvey Lodish of the Whitehead Institute has called for an expanded role for new commercial ventures in moving science education forward. He likens the development and marketing of new educational tools to the exploitation of DNA technology by new biotechnology firms. "Much excellent teaching material is being developed at individual institutions," he said, "but it needs a commercial organization to test, refine, and market the product." Lodish is involved in a new publishing house created to do just that: Cogito Learning Media, Inc. Its founder and president, Linda Chaput, points out that commercial developers interested in market appeal have to start with technology that is already in widespread use, which currently means video and CD-ROM. Whether undertaken in a university or a corporation, the important task of developing multimedia tools works best when carried out by a well-coordinated team of inventors with a unique blend of talents. We learned this firsthand at the Institute in building HHMI's World Wide Web site. The term multimedia, we found, is in some ways a misnomer. This is not just a combination of media, but a new medium unto itself. It requires a new, nonlinear way of looking at organizing information and a multicultural team that can do everything from graphic design to punching in program code. As our project developed, we found that we needed the skills of graphic artists, computer programmers, writers, and editors. We also found that designing a clear, efficient, attractive, and easy-to-use web site is a problem not quite like any other, and one that demands careful thought.

Like other developers of computer tools, we also found that our project took longer than expected. As someone said of computer projects, "the first 10 percent of the project takes 90 percent of the time, and the rest of the project takes the other 90 percent." In the end, however, it will be worth the investment. The HHMI site, we believe, will improve our community outreach, foster collaboration among scientists and educators, and someday speed grant applications.

Just as the molecular revolution in biology has bolstered the life sciences at colleges and universities, so too will the revolution in educational technology bolster the value and impact of good teachers and their ability to connect with their students.

Educational technology has the power to individualize instruction, but it must be used thoughtfully. It should not supplant contact between faculty and student, or collaboration with student peers. The goal is to improve significantly the quality of learning through new information technologies. This advice applies not only to technology, but to all innovations in science education.

J.K. Haynes, of Morehouse College, challenged us all to consider the following when pursuing the attraction of educational technology: (1) that we develop learning skills and not just put textbooks on line, (2) that we recognize the need to gear educational technologies to different learning styles; (3) that innovative educational technology might be most effective for nonscience majors, who need science to be more "user friendly," (4) that we understand the limits of time and resources in faculty efforts to change teaching behaviors, and (5) that we need sound assessment of educational technologies.

In 1995 Eli Noam wrote in *Science* that higher education must face its changing role in society if it is to survive in the information age.[8] The question is not whether universities are important to society, to knowledge, or to their members—they are—but rather whether the economic foundation of the present system can be sustained as electronic communications change the flow of information. It is not research and teaching that will be under pressure, but rather their instructional setting, the university system. "In the validation of information, the university will become more important than ever. With the explosive growth in the production of knowledge, society requires credible gatekeepers of information, and has entrusted some of that function to universities and its resident experts, not to information networks."

There is a gap between having technology and using it effectively. As the technology evolves, so must our wisdom in how to use it.

[8] Noam, Eli M. Electronics and the dim future of the university. *Science* 270:247–249, 1995.

Only Connect

The novelist E. M. Forster told young writers who wish to pursue writing as a career that they must "only connect." Reaching and teaching students will be increasingly enhanced by digital circuitry. Just as the molecular revolution in biology has bolstered the life sciences at colleges and universities, so too will the revolution in educational technology bolster the value and impact of good teachers and their ability to connect with their students. With the right tools, people will become learners for life—from childhood to old age!

It is unlikely that we will ever confront a "Hal," the supercomputer of 2001 who overrode the intent of its human counterparts. But one can foresee a rising generation of computer-literate, computer-sophisticated students who will expect their professors and mentors to guide them through ever-growing masses of information. There is a gap between having technology and using it effectively. As the technology evolves, so must our wisdom in how to use it. And possibly more important is the issue of access. If what we suspect is true—that educational technology has the power to transform and improve dramatically the way we teach science—then we must ensure its accessibility to all who seek it. That means investment not only in technology but in its users: teachers and students. HHMI is trying to lead in this area through example and commitment.

Overview of the Undergraduate Biological Sciences Education Program

Since 1988 the Institute's Undergraduate Biological Sciences Education Program has awarded $290 million in grant support to 213 colleges and universities for undergraduate science education (Figure 1). The goal of this program is to support efforts to strengthen the national quality of college-level education in the biological sciences and other scientific disciplines as they relate to biology. Another important objective is to support outstanding programs that seek to attract and retain students in scientific fields, including women and members of minority groups underrepresented in the sciences.

Institutions have been invited to participate in the undergraduate competitions on the basis of their recent records of having graduated students who went on to medical school or to earn Ph.D.'s in biology, chemistry, physics, or mathematics. Data for these assessments were provided by the Association of American Medical Colleges, the National Research Council of the National Academy of Sciences, and the U.S. Department of Education (Figure 2).

To identify institutions as eligible to be included in each assessment, the Institute has referred to the classifications of higher-education institutions by the Carnegie Foundation for the Advancement of Teaching (1987 and 1994). These classifications are based on such factors as the level of degree offered, nature of the educational mission, degree of specialization in particular fields, and amount of annual federal support for research and development. The Institute has also taken into account institutions' records of preparing students from minority groups underrepresented in the sciences to pursue scientific careers.

Proposals are reviewed by an external panel of distinguished scientists and educators. The panel's evaluations, in turn, are reviewed by an internal Institute committee that makes recommendations to the Institute's Trustees, who authorize funding. Through its ongoing assessment of the undergraduate program, the Institute has developed the program to respond

Figure 1

Undergraduate Competitions (1988–1994)

1988: 44 public and private comprehensive and liberal arts colleges and universities were awarded $30.4 million in grant support for their science programs

1989: 51 public and private research and doctorate-granting universities received $61 million to enhance undergraduate science education

1991: 44 public and private comprehensive and liberal arts institutions were awarded $31.5 million in grant support

1992: 42 public and private research and doctorate-granting universities were awarded grants totaling $52.5 million

1993: 47 public and private comprehensive and liberal arts institutions received grants totaling $28.5 million

1994: 62 public and private research and doctorate-granting universities received grants totaling $86 million to national needs in undergraduate science education.

In its first phase of operation (1988–1992), the undergraduate program supported programs of student research and broadening access to science; science faculty development; equipment, and curriculum and laboratory development; and outreach programs linking science departments with community colleges, elementary and secondary schools, and other institutions. In its second phase (1993–1994), the program continued its support of student research and broadening access activities and precollege and outreach programs, and included an increased emphasis on laboratory development through equipment and renovation support.

In 1995, the third program phase began, with invitations to institutions classified as Baccalaureate Colleges I and II, Master's Colleges and Universities I and II, and Schools of Engineering and Technology to compete for grants to be awarded in 1996. Invitations will be issued in 1997 to institutions classified as Research Universities I and II and Doctoral Universities I and II to compete for grants to be awarded in 1998. In this phase the Institute will continue its support for student research and broadening access to the sciences, equipment and laboratories, and precollege and other outreach programs. Based on information collected through assessment activities, the program includes support once again for faculty and curriculum development in the Phase III competitions.

Of the $290 million awarded to date, a total of $103.5 million supports students in summer and academic-year laboratory experiences on and off campus, as well as prefreshman bridging programs, laboratory training, opportunities for students to present their research at scientific meetings, and other activities that promote a culture of science at the undergraduate level. In the area of curriculum and laboratory development and equipment, a total of $93 million supports the enhancement of undergraduate science education through the acquisition of modern teaching equipment, renovation of laboratories, and development of science curricula and educational

Figure 2

Assessment Criteria

To identify institutions for participation in the undergraduate biological sciences education program competitions, the Institute conducted assessments covering the most recent 10-year period for which data were available. Based on data on total baccalaureate degree production collected by the U.S. Department of Education, institutions were assessed on the basis of the percentage and absolute number of graduates from each institution who have

Matriculated in Medical Schools

Data source: Association of American Medical Colleges

Earned Doctorates in Biology

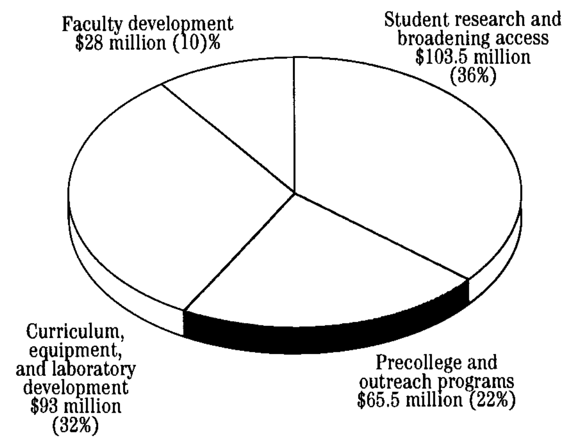
Data source: National Research Council of the National Academy of Sciences

Earned Doctorates in Chemistry, Physics, or Mathematics

Data source: National Research Council of the National Academy of Sciences technology. A total of $28 million supports the appointment of new science faculty members and opportunities for existing faculty members to broaden their knowledge base or update their teaching skills. A total of $65.5 million supports science outreach programs for faculty members, teachers, and students at two-year and four-year institutions and secondary and elementary schools (Figure 3).

Figure 3

Awards to 213 Colleges and Universities ($290 million) by Program Component, Phases I and II, 1988–1994 Competitions



Keynote Address

Two Cultures Within the Scientific Revolution: Teaching and Research in Biology

Harvey F. Lodish, Ph.D., D.Sc. □ Member, Whitehead Institute for Biomedical Research □ Professor of Biology, Massachusetts Institute of Technology

Last year's lecture by Sheila Tobias focused on two cultures—the worlds of science and liberal arts. Dr. Tobias talked of the need of scientists to explain science and the scientific method to nonscientists, as well as the importance of teaching the development of ideas, and not just ideas.

Today, I plan to discuss a different set of cultures—research and teaching in the scientific community. I think these two cultures are much less noticed. Teaching is the antithesis of research in some ways. Yet, teaching and research should be part of the same enterprise.

My thesis is that research should be an integral part of teaching at all levels, particularly at the early college level. It is important to get the most recent and the most exciting science in the hands of the very beginning students.

Teaching itself benefits research. Teaching forces us as research scientists to look beyond our narrow sphere of expertise and think more broadly. There is an advantage in constantly being challenged by young students who ask not only why, but why not. Often they are much smarter than I am and ask very interesting questions. Teaching helps researchers give better research lectures. The U.S. college education system is highly regarded throughout the world because it is able to integrate teaching and research at the graduate and postgraduate levels.

Throughout most of the world, teaching and research are kept separate. I noticed this at Cambridge University in England when I did postgraduate work with Francis Crick at the Medical Research Council's Hills Road facility. The researchers gave lectures at the university, but students were forbidden to go! At the Max Planck Institute in Germany, research is kept separate from teaching. In France, professors at universities have heavy teaching loads, whereas none of the researchers at the institutes do.

Three Great Strengths of the American Educational System

- □ After World War II in the United States, research universities evolved to mix teaching and research at the undergraduate and graduate levels.
- □ Small liberal arts colleges, which are unknown outside the United States, harbor a devotion to teaching. They

In his keynote address, Dr. Lodish remarks that the success of undergraduate science education hinges upon the integration of research and teaching, with technology playing a critical role in teaching students scientific concepts and techniques.

are also more able to carry out multidisciplinary teaching that promotes innovation in teaching, and as the teaching paradigm has changed, research has become an integral part of undergraduate science education. In the past, lectures were combined with cookbook experiments in the laboratory. Now, upper-level courses are being replaced by research projects. These colleges are a unique American invention, and they produce a disproportionate share of scientists.

- Private colleges and universities are also an American invention. They have the freedom to develop new curricula, test ideas, and encourage innovation. They are free of government bureaucracy. There are no private research universities in Europe, with the exception of Oxford and Cambridge. When I was an adviser to Biozentrum, I met with the education ministers of two cantons in Switzerland, where it literally requires an act of parliament to appoint a professor. This makes it difficult for countries as a whole to move quickly into new fields. Governments are very good at insisting on uniformity and stifling creativity.

Research as an Integral Part of Teaching

Part one of my thesis is that research is an integral part of teaching. Science needs to be made more accessible and enjoyable for all undergraduate students. Biology is now the most attractive of the sciences, partly because of the Human Genome Project and many other advances in human biology, the explosion in biotechnology, and increasing understanding of the importance of ecology.

My principal aim in teaching and writing about biology is to put cutting-edge science into the hands of undergraduate students so that they can understand how science is actually done and how it affects their lives. Why? Science is an ongoing enterprise. Ideas and results and techniques are constantly changing.

The Massachusetts Institute of Technology now requires biology for all undergraduate students. The impetus came not from biologists, but from the business school, engineers, and physicists. New methods of drug delivery, tissue engineering, and gene therapy have completely altered the way we think of science and research. Developing and using growth hormone in fish will change fish production. Chemicals become environmental contaminants and cause cancer. You cannot function as an informed citizen in modern society without some basic understanding of the fundamentals of science—genes, molecular biology, proteins, cells—and the way research is done.

Understanding the process of science affects all students, not just the ones who will become scientists. Science teachers must present the orderly logical analysis of a problem—the thought process rather than the result. They must explain integrity in science. At the leading edge of scientific research, people can often come to the wrong conclusion simply because they do not understand all of the parameters, not because of fraud or misrepresentation. Scientists today cannot do a single experiment, solve a problem, and go on to the next problem.

Students do not have a sense of how science works. They should learn how to develop a hypothesis, design an experiment, and interpret data. They should learn to ask the *why* about a problem, not just learn the technology.

It is important to understand biology and how it is different from other sciences, such as chemistry, physics, or mathematics. Biology requires an understanding of a large number of details. However, too many textbooks and teachers tend to be encyclopedic and fail to emphasize the fundamental principles. I will devote a good part of my talk to detailing the philosophy that underlies my own approach to teaching biology.

Teaching Biology: My Approach

Part of my philosophy about teaching biology is that it is an experimental science, and the facts in biology are only as good as the experiments that support them. Unlike math and physics, biology is not built on theorems. Biology evolved. We are all the result of biological evolution. Because of accidents and ecological pressures, we carry with us a biological historical record. Merging these details and principles is important.

Another part of my philosophy is that molecular and cell biology, and recombinant DNA in particular, are now at the center of all biological research. What unites all biological organisms is far more important than what separates us. A pine tree, a mouse, and a yeast cell used to be studied for their unique properties in the disciplines of botany, zoology, and microbiology. Now we focus on the unifying elements: genes, proteins, and cells.

This can be illustrated in a triangle, where proteins, genes, and their functions form the points of the triangle. Molecular biology is found between protein and gene. Genetics is found between gene and function, and biochemistry is found between protein and function. This is all part of a continuum, and we need to teach biology so that it reflects these common principles.

The third part of my philosophy is that teaching and research go hand in hand. The most effective way for students to learn and appreciate the facts of biology is to experience and understand the way these facts were derived.

The fourth part is that biology is now an analytical science, much like mathematics, chemistry, and physics, and a good way to learn biology is to solve problems. But problem-solving should not be an end in itself. Students must learn the *why* behind the *how*—the concepts and not just the techniques. I have become very conscious of teaching and learning to ask the *why* questions.

Teaching as an Integral Part of Research

This brings me to the second part of my talk: teaching as an integral part of research. Teaching and research are part of the same enterprise. Students are often the ones who generate new ideas and ask key questions. It is important for the progress of research to get the top students in contact with the top scientists.

To do this, you must break down the barriers between the two classes of scientists—teachers and researchers—and make the researchers teach at all levels. Most medical school faculty teach less than five hours a year. Not only is it a disgrace, but it may hurt their research in the long term—pure research institutes can become stagnant.

The genius of Jack Whitehead and David Baltimore emerged when they made a new institute an integral part of a research university and required researchers to be involved in teaching at undergraduate and graduate levels. Four members of the Whitehead Institute teach introductory biology at MIT.

A good example that validates this whole notion is that of a graduate student in my laboratory and a postdoctoral student in Dr. Robert Weinberg's laboratory who saw an opportunity to combine techniques and expertise to isolate an important pair of genes—the receptors for transforming growth factor beta. They went off and did this without telling Bob or me exactly what they were doing, and their results are the 14th most cited paper published in 1992!

Having undergraduates in the laboratory is wonderful. Undergraduates are fearless. They will take on projects that graduate students will not take on. For example, an undergraduate made about 30 new mutants of the erythropoietin receptor, a massive undertaking that he did just because he did not know any better.

The strength of this approach —combining research and teaching—tends to equalize the two. Half research and half teaching is almost unique in the American institution. A colleague who heads a major cancer research institute in London told me that he wishes that his faculty would teach 10 to 15 lectures a year. It would broaden their research interests, make them more aware of opportunities in related fields, and expose students to research scientists.

Also, teaching helps researchers organize and deliver better research lectures. Many researchers do not recognize that delivering research seminars is just like teaching a class—holding the interest of the audience, explaining complex materials in a simple way, and leaving the audience with take-home messages that contain the key summary points of the talk. Many outstanding scientists at purely research institutions have trouble with this and would benefit from regular teaching.

Developing Teaching Materials: From Books to Multimedia

In the last part of my talk, I want to explain why I decided to write a textbook 15 years ago. New techniques of molecular biology were unifying all experimental biology. A clear hierarchy was emerging—molecules, macromolecules, organelles, cells, tissues, organs, organisms, communities, and ecosystems. The once-separate fields of biochemistry and molecular biology, genetics, cell biology, physiology, developmental biology, and much of neurobiology were wedded by recombinant DNA and other fundamental experimental approaches.

My book fundamentally explains how things are derived and the key concepts that guide this. It provides the facts that underlie the different fields of biology and explains how these facts unify the fields. It explains the interrelationship of structure and function. It gives students and researchers the wherewithal to understand how science is done—the basic concepts, experimental techniques, and experimental organisms.

The book focuses on three very general key issues: control of gene expression, the structure and function of proteins that carry out specific biologically important tasks, and understanding the properties of proteins and the other molecules they contain. The emphasis is on the fundamental experimental tools and techniques that underlie the newly integrated science of molecular cell biology.

When writing books, we have to be careful to include material that is generally accepted by the community. As evidence of the fast pace of research, some things in the second edition were proven wrong almost immediately before the book was published.

From writing this book, I have moved on to become a founding adviser to a new commercial publishing company dedicated to producing textbooks, videos, and, most importantly, computer-based teaching materials for use in introductory college science courses. This is why: Textbooks, for the most part, are encyclopedic and boring. They are out of date by the time they are published. Often one author copies from another—particularly figures—without realizing that some of the material may be wrong or out of date.

Excellent video and compact disk teaching material exists for kindergarten through sixth grade and a bit beyond, but there is little such material for the advanced high school or early college level. Students are surfing the Internet in 10th grade, but there is not yet a mass of material for them to use.

Why an entrepreneurial approach? When advances in biotechnology occurred, particularly the development of proteins as drugs (erythropoietin, growth hormone, interferon, granulocyte colony-stimulating factor, etc.), existing pharmaceutical companies missed out on these developments because they were not equipped to move quickly into new areas. They did not have people on staff who understood the impact of this new technology. People outside these companies exploited the technology.

The same is so with publishing. Existing publishing companies are too bureaucratic, too unwilling to make radical changes, and too unfamiliar with current research activities. This enterprise must be commercial. Much excellent teaching material is being developed at individual institutions. A commercial organization is needed to develop, test, refine, and market these products. It is analogous to founding a biotechnology company. When universities developed new therapeutic proteins or drugs, they were not equipped to develop, test, and market the product. They needed a relationship with commercial entities.

We are the only educational publishing company with a scientific advisory board that is more than ceremonial. We are driven by science and by the need to make state-of-the-art material available for beginning college students. One example is our series on experimental organisms—why scientists pick particular organisms or systems to investigate particular topics. These include bacteria for basic studies of DNA and gene structure and function, mice as the closest organisms to humans that can be manipulated, and yeast as simple eukaryotes. This is underscored by the unity of evolution and the idea that we must have evolution as the basis of all biological understanding.

These topics will be published as video CD-ROMs that provide interactive questions for students. This kind of thing is important to do and make accessible to students anywhere. The World Wide Web is one way. Computer-based educational material is another. When you see our first videos, think of the student just beginning college. Only you can tell us whether or not this is successful. These videos are not stand-alone material. They will need teachers to explain what is going on or students using interactive CD-ROMs.

Teaching and Research—Part of the Same Enterprise

I believe that all undergraduates should have some exposure to what is happening in science and the current excitement in science. They should be formulating hypotheses, testing them, and doing experiments. Research is at the core of science. The truth is constantly changing as techniques are constantly changing.

Students who are encouraged to keep a lifelong interest in biology will be much more informed members of society. Students must know that the kind of training I have in mind can be used in lots of fields: patent law, business, film-making, and journalism. If we did nothing but train science students to go into elementary and high school and teach other students what they know, this country would be a better place. Of course, we must encourage students to go into science, particularly the ones who are interested and able in research.

I feel privileged to have had the opportunity to participate in the development of modern molecular and cell biology and biotechnology. Having had very good teachers and mentors, I feel an obligation to pass on to following generations the excitement of doing research. Teaching and research are all part of the same enterprise.

Discussion

Most Effective Approaches to Teaching Biology. Dr. Paul Grobstein, Bryn Mawr College, questioned Dr. Lodish's teaching approach of going from the specific to the general. He said that in his experience it is difficult to persuade students to learn a large amount of factual material before the material is presented in a relevant context. For this reason, he said, his institution's approach was to "start with organisms and use the students' natural curiosity to motivate discussion of other things." Dr. Lodish responded that MIT's approach—to begin by teaching genetics and progressing to the Human Genome Project—was not the only way to do it, but that it seemed to attract students' interest.

Dr. Lodish added that his company uses this approach—relating scientific research to human processes—in the videos it produces. For example, one video describes how researchers isolated a genetic mutation that controls cell division in yeast and points out that because the defect is lethal in mice, it cannot be studied in that organism. The video concludes with an interview with Dr. Shirley Tilghman, HHMI Investigator at Princeton University, who explains that many of the genes that cause colon cancer in humans are homologous to the defective yeast gene.

In response to a question by Dr. John Palka, University of Washington, Dr. Lodish said that he did not use this model to teach about interactions between organisms. "A whole different level of thought processes goes into teaching ecology," he said.

Comments on Video. Dr. Don Dennis, University of Delaware, said that the video shown by Dr. Lodish effectively illustrated the tools used in technology but gave students no idea how to use them. Dr. Christopher Mathews, Oregon State University, expressed concern that the video might give students the impression that there was very little left to be discovered in scientific research.

Dr. David Burgess, University of Pittsburgh, said that the video and other interactive multimedia products that Dr. Lodish intends to produce would help to make students into active rather than passive learners. Dr. Hillel Chiel, Case Western Reserve University, commented that the video gave no indication of the uncertainties inherent in the research process.

Ms. Linda Chaput, of Cogito Learning Media, Inc. (formerly Interactive Sciences, Inc.), the company that produced the video, said that the company had chosen to make videos because most schools have the technology to show them, whereas many schools are not yet equipped to use interactive technologies. She added that the company ultimately plans to move the video modules to interactive CD-ROM format.

Dr. Lodish said that he regards the computer-based instructional materials produced by his company as teaching enhancements; they are not intended to stand alone. The materials enable students to see the research process and hear researchers discuss their work. "Society as a whole does not understand what goes on in a research lab," he said.

He said that he intends to develop a videotape series about commercial techniques in biotechnology and to incorporate a sense of the uncertainties of research into CD-ROM–based materials in which students will be able to analyze research problems and make decisions about how to design and conduct experiments.

Institute president Dr. Purnell Choppin commented that the concept of failure is built into the word "re-search." Dr. Joseph Mascarenhas, State University of New York at Albany, observed that the marketplace will ultimately decide whether the kinds of technology being developed by Dr. Lodish and his associates will be used successfully in science education.

Biographical Sketch Harvey Lodish

Dr. Lodish received his A.B. degree in chemistry and mathematics, summa cum laude, from Kenyon College in 1962 and his Ph.D. degree in genetics (with Dr. Norton Zinder) from the Rockefeller University in 1966. Following two years of postdoctoral research at the Medical Research Council's Laboratory of Molecular Biology with Drs. Sydney Brenner and Francis Crick, he joined the faculty of the MIT Department of Biology. He was promoted to professor in 1976 and in 1983 was appointed as a member of the new Whitehead Institute.

Initially, his work focused on translational control of protein synthesis and on regulation of gene expression during differentiation of the cellular slime mold. Since 1973, his laboratory has increasingly concentrated on the biogenesis, structure, and function of secreted and plasma membrane glycoproteins. He defined the biosynthesis and maturation of the vesicular stomatitis virus glycoprotein, identified the intracellular organelles that mediate recycling of the asialoglycoprotein and transferrin receptors, and clarified the role of pH changes in delivery of iron to cells and recycling of the transferrin receptor.

More recently, his group has elucidated steps in folding and oligomerization of several proteins within the endoplasmic reticulum, shown that exit of newly made proteins from this organelle requires that they be properly folded, and developed probes for measuring the redox state within the endoplasmic reticulum. His group has cloned and sequenced mRNAs encoding the erythrocyte glucose transporter, the anion exchange (Band 3) protein, a transporter for free fatty acids, the human asialoglycoprotein receptors, intestinal sucrose-isomaltase, the murine erythropoietin receptor, the calcitonin and endothelin receptors, and two subunits of the transforming growth factor beta receptor. These have been used to define the structure and synthesis of the proteins, to identify and sequence related genes that encode proteins of related physiological function, and, most recently, to elucidate the modes of signal transduction of the transforming growth factor beta and erythropoietin receptors and their roles in tumorigenesis.

Dr. Lodish is on the Board of Reviewing Editors of *Science* and was editor of *Molecular and Cellular Biology* from 1981 to 1987. He has been on the editorial boards of a number of journals, including the *Journal of Cell Biology*, the *Journal of Biological Chemistry*, and *Nucleic Acids Research*. He is an author of the textbook *Molecular Cell Biology*.

He has served on advisory panels for the National Institutes of Health, the National Science Foundation, and the American Cancer Society and on the advisory boards of several institutions, including the Biozentrum of the University of Basle and the European Molecular Biology Laboratory in Heidelberg. He is currently on the advisory board of the Pew Scholars Program in Biomedical Sciences and is a member of the Kenyon College Board of Trustees. He is chair of the advisory boards of the Division of Basic Sciences of the Fred Hutchinson Cancer Center and the Cleveland Clinic Research Institute and chairs the International Committee to Evaluate Biochemistry in Denmark.

Dr. Lodish is a member of the National Academy of Sciences and a fellow of the American Association for the Advancement of Science. He is an associate member of the European Molecular Biology Organization and a fellow of the American Academy of Microbiology. He is the recipient of a Guggenheim Fellowship, an honorary D.Sc. from Kenyon, and the Stadie Award from the American Diabetes Association.

A founder and scientific advisory board member of Damon Biotech, Inc., and Genzyme, Inc., Dr. Lodish is currently an advisory board member of Arris Pharmaceuticals, Inc., Astra AB, and Millennium, Inc. Most recently, he is a founding adviser to Cogito Learning Media, Inc., which develops and publishes video and computer-based instructional material for introductory college science courses. The company's home page is at <http://www.cogitomedia.com>.

Improving Access to Science Through Educational Technology

Presentations during the first session focused on the use of educational technology to improve access to science, not only for undergraduates at grantee institutions but also for elementary and high school teachers and students, especially those in disadvantaged or isolated areas.

During the plenary panel discussion, three program directors described the level of technological development at their very different institutions. One is just beginning to incorporate educational technology into teaching and is grappling with such issues as whether software should be geared to learning styles. Another has successfully integrated technology into its introductory-level courses, and a third has a well-established technology base but is looking critically at the national technological infrastructure.

Although a variety of approaches and strategies were described, certain common features and objectives emerged. Presenters and discussants generally agreed that it is crucial to teach science in a way that excites students. One program director said that the aim of her institution's science curriculum–reform effort was to recreate the thrill of discovery that had led faculty members to embark on careers in science. Several speakers described initiatives in which students learn science by doing science in ways that simulate the process of scientific research.

The role of educational technology in stimulating excitement about science was the subject of much discussion. Some meeting participants expressed concern that students in innovative science courses emphasizing discovery would absorb less content than students in more traditional courses and would be placed at a disadvantage when taking standardized tests. Others felt strongly that students exposed to nontraditional teaching approaches achieved a better understanding of scientific concepts and had a more positive attitude toward science than their counterparts who had not had such exposure.

Efforts to devise new tools to better evaluate the effectiveness of technology-based teaching were described and reference was made to the large amount of data gathered from corporate America and the U.S. military on the effectiveness of technology-based learning.

Participants also debated the extent to which electronic simulations can replace hands-on laboratory experience and whether hands-on experience is as important for nonscience majors as for science majors. Other issues touched on included the impact of educational technology on faculty, the role of faculty members in using and developing such technology, and the challenges of funding the installation and maintenance of sophisticated computer networks and telecommunications systems.

An especially potent use of technology is to build virtual communities that overcome barriers such as geographic isolation. Several speakers described programs that have successfully used technology to reach out to teachers in rural areas. Technology can also provide long-distance learning for students isolated from college and university campuses.

Educational technology appeals to students with a broad range of learning styles and can be especially attractive to visually oriented learners. The interactive, investigative, self-paced nature of technology-based courses may also appeal to students who are not attracted to traditional science courses that emphasize the rapid absorption of large amounts of factual material.

Improving Access to Science Through Educational Technology

Morehouse College □ J.K. Haynes, Ph.D., Moderator
University of California–Los Angeles □ Orville Chapman, Ph.D.
Wellesley College □ Mary M. Allen, Ph.D.

Morehouse College

Dr. Haynes said that a long-term goal at Morehouse College has been to get science students involved in research. Because of that priority, most of the college's HHMI funding has been spent on state-of-the-art laboratory research equipment rather than on educational technology.

Research-quality equipment permits sophisticated data collection and interpretation and facilitates active investigative laboratory studies. Incorporation of computers and modern laboratory technology in courses helps to ensure that students are thoroughly familiar with the concepts, instrumentation, and methodology of present-day biological experimentation.

Computers are used in a dedicated electronic classroom and in wet laboratories to provide supplemental materials for courses in cell biology, molecular genetics, physiology, biochemistry, plant sciences, and ecology. The electronic classroom holds 25 Apple Macintosh computers networked with a laser printer and a color inkjet printer. Each computer is loaded with word-processing software in addition to course-specific programs.

Instructional software is used for subject reviews and self-tests. Computer software enables biological-process simulations and dry laboratory simulations before wet laboratory studies. Statistical analysis software is used for analyzing data and preparing presentation graphics in the ecology laboratory and biostatistics courses. Dr. Haynes remarked that in general, he was not impressed with the educational software presently available.

Dr. J.K. Haynes of Morehouse College moderates the opening plenary session on improving student access to science through educational technology.

University of California–Los Angeles

As faculty members consider applying the new technology to their institutions, Dr. Chapman noted that perhaps it was appropriate to look at current technological changes in the academic world. He then provided some historical perspective.

Dr. Chapman compared the reluctance to accept technology by some in the academic world with Plato's reluctance to accept writing because he felt that it destroyed the oral tradition and with the reluctance of the Ottoman Empire and most of Asia to accept the 16th century's new technology, the textbook.

There is a danger for everyone in ignoring technology-based learning, Dr. Chapman said. He suggested that there are four levels of faculty acceptance of technology: The first is outright denial. The second is using technology to add a visual element to lectures. The third is students using interactive technology outside the classroom. The fourth is students using technology that enables exploration and discovery.

Learning based on information technology encompasses not just a computer, but a whole package. Students learn science by doing science. Hearing someone only talk about science never works; students must be involved in asking questions and solving problems, Dr. Chapman said. At the University of California–Los Angeles (UCLA), students work in groups of three, using very high quality technology-based equipment. They publish their work on a computer network so that faculty members can evaluate their learning.

Students use the technology in various ways, including designing molecules and calculating their properties in the laboratory. They don a virtual-reality helmet to knock atoms off a silicon wafer projected by a scanning tunneling microscope. They use the Internet to set up the Wilson telescope one day and download data the next. If they need help in interpreting the data, they contact astronomers at UCLA or Kent State. The important component of all of this technology is that it is interactive and motivating. The problem with lecture, animation, and video is that the student does not actively participate.

According to Dr. Chapman, several changes must take place to modernize the American educational system. First, the United States must create a high-speed broadband technology infrastructure, such as is found in Singapore, Hong Kong, and Japan. Without this, the United States may miss the technological boat in education just as the Ottoman Empire did with textbooks.

Second, assessment methods must change. A huge library on the effectiveness of technology-based learning is available from corporate America and the U.S. military. Third, student and faculty culture also must change. Students must stop memorizing and start doing things. Students can drive that change, and they are the most convincing motivation for faculty.

UCLA's Science Challenge reaches 15,000 students every year, 9,000 of whom are science majors. Fifty information modules and a videotaped research lecture series have been created. In the United States the modules are used by college freshmen and sophomores. In Europe and Japan the same modules are used by high school students.

UCLA has downsized faculty and staff by 10 percent; another 40 percent decrease is scheduled to occur by 2000. This trend is sweeping the United States. Education, the nation's second largest industry, is downsizing. Dr. Chapman said that the Internet is the competition: not only will it open up the possibility of distributing courses to the world, but a commercial entity can offer a virtual global university. "We're facing a different market in the 21st century," he said. "We have to learn to do better with much less."

Wellesley College

The use of computer-aided technology at Wellesley College helps faculty members to teach better and create a better learning environment for students, said Dr. Allen.

Introduction to Collaborative Interdisciplinary Problems and Intellectual Tools (Incipit) is an interactive program designed by 14 faculty members from 11 academic departments. Incipit enables students to look at proteins across a series of mammalian species, become familiar with molecular biology, and think about molecular biology in terms of evolutionary change. DNA sequences are downloaded from the World Wide Web, and students look at the structure of proteins coded by this DNA. According to Dr. Allen, many of the nonscience majors were amazed at what they were able to do and what it meant in terms of evolution.

In introductory chemistry, students use Hyperchem software to test molecular models, look at complex systems, and think about structure and reactivity. They can predict bond angles, carry out calculations, and compare results. Beginning biology students are using Biology Explorer, another commercial software package, to plot data from their experiments and model variables that are im-

Dr. Orville Chapman, University of California–Los Angeles, listens as Dr. Mary Allen, Wellesley College, tells how computers are part of a broad strategy at her institution for strengthening students' quantitative skills and teaching advanced techniques such as molecular modeling.

possible to obtain in their laboratory work.

For example, students experiment with two variables by growing sunflowers in shade and sun. After three weeks, they process the leaves to measure transpiration and oxygen evolution and plot their results by computer. Then, they incorporate variations of humidity, temperature, and water and carbon dioxide levels over time, which they cannot do in the laboratory because it would take years to gather the necessary data.

So far, more than 500 biology majors and nonmajors taking the college's two introductory biology courses have used the software for modeling problems in population biology, genetics, respiration, and circulation. Dr. Allen noted that student response has been overwhelmingly positive.

The whole culture of science teaching and learning has changed, said Dr. Allen. Students become responsible for their own learning in many ways: they learn problem-solving skills and begin to ask their own questions and work out the answers themselves. They come away with a feeling of power that they apply to subsequent courses. Working in pairs, they also learn how they make mistakes in their calculations, and the experience helps them appreciate the limitations of modeling. It gives them a glimmer of how research really works.

Discussion

Assessment of Computer-Based Learning Materials. Dr. Joseph Mascarenhas, State University of New York at Albany, asked Dr. Chapman whether UCLA had assessed the quality of learning by students participating in the Science Challenge program. Dr. Chapman responded that two cognitive psychologists had assessed students' attitudes toward science and their level of attainment.

Attitudes toward science improved radically, he said, especially among young women. Comparisons of students' level of attainment showed no difference compared with traditional approaches. However, Dr. Chapman noted that programs like Science Challenge are oriented to increasing students' understanding of the material and that available tests are not designed to measure understanding.

In response to Dr. Shirley Raps, City University of New York Hunter College, who asked how students could be prepared for Graduate Record Exams or MCATs if memorization of material was no longer required, Dr. Chapman noted that many tutorial programs exist to prepare students for these examinations.

Simulations vs. Hands-on Laboratory Experience. Dr. Alice Burton, Saint Olaf College, asked Dr. Allen whether simulations had replaced hands-on experience in wet laboratories. Dr. Allen replied that Wellesley students perform hands-on experiments first and then use computer simulations to model experiments that cannot be performed in the laboratory because of time and equipment constraints or because of their complexity.

Dr. Haynes said that laboratories are quickly becoming non-cost-effective for students who are not science majors. This comment sparked a lively discussion about the merits of replacing wet laboratories with computer simulations. Dr. John Palka, University of Washington, said that although simulations may be a helpful adjunct, medical students need wet laboratory experience to obtain a sense of an organism.

Dr. Hillel Chiel, Case Western Reserve University, used a cabinet-maker analogy: An interactive CD-ROM could show people how to design and build a cabinet and virtual reality could enable them to experience what the inside of a cabinet felt like, but "you still need hands-on experience [to build a cabinet]. You can't replace that."

Dr. John Ritchey, Fort Lewis College, said he was concerned that students who are only exposed to computer-based learning are not "grasping what excited me about science." Dr. John Jungck, Beloit College, agreed that students need experiences in a world with live organisms. Dr. Don Dennis, University of Delaware, suggested that computer simulations may be sufficient for nonscience majors but that science majors need hands-on experience as well. Dr. Chapman commented that nonscience majors might benefit more from exploring databases of research results than from actual laboratory experiences.

Role of Universities in a Computer-Networked World. Dr. Chiel observed that one of the effects of new technology on education is that people no longer have to come to universities to learn. "Now the knowledge goes to where they are." However, he added, human interaction remains critical for helping students to distinguish between information and data and to develop research skills by working alongside experienced researchers. Dr. Chapman argued that universities "have to remake themselves from the ground up" to accommodate the realities of a high-technology world.

Dr. Martha Crunkleton, Bates College, said that the crucial issue for institutions of higher learning is to generate greater public support for science education by improving science literacy in the general population. "The lack of public support for learning reflects how we teach science," she said. "We must teach the ability to distinguish information from knowledge and wisdom. Whether we do it with the computer or wet lab is not the question."

Group 1: Electronic Outreach: Building Bridges to Teachers

Cornell University ☐ Peter J. Bruns, Ph.D., Moderator
College of the Holy Cross ☐ Frank Vellaccio, Ph.D.
Washington State University ☐ John Paznokas, Ph.D.
Access Excellence/Genentech Inc. ☐ Geoffrey P. Teeter, Resource

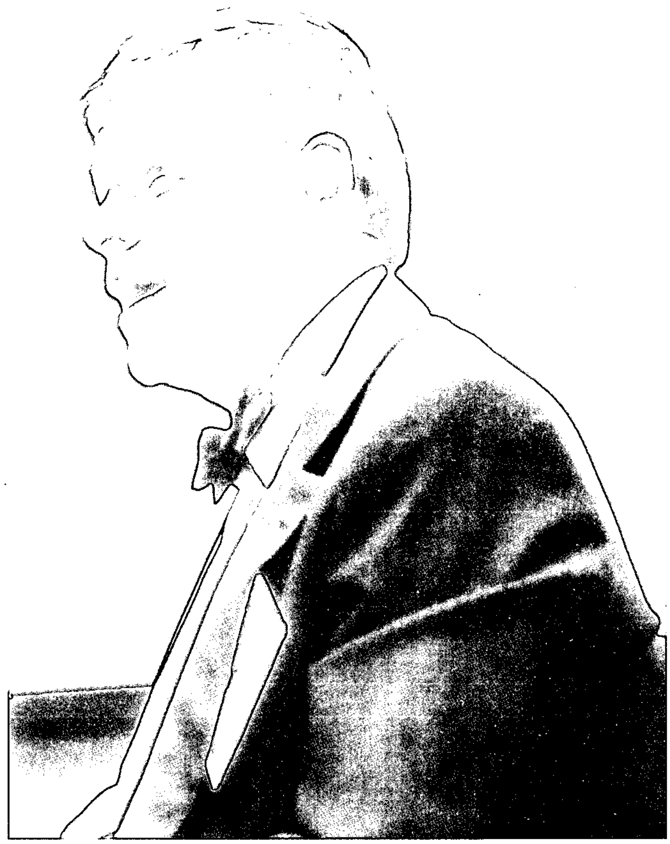
Cornell University

Isolation from colleagues is a major problem faced by many teachers, especially those in rural high schools. Cornell University, which has sponsored a three-week summer program for high school biology teachers for seven years, sends each participant home with a modem-equipped computer and Telefinder communications software. These teachers become instant members of the Cornell Institute for Biology Teachers Network (CIBTnet).

Teachers access CIBTnet from home by calling a computer at Cornell, which quickly hangs up and calls back to minimize the cost of the call to the teacher. Most of the 144 teachers on the network call CIBTnet once a week and stay connected, on average, for 8.7 minutes. They use the network to schedule equipment loans from the university biology department, ask scientific questions of Cornell's faculty members, peruse a list of teaching positions, participate in public discussions on programs and issues, and download teaching materials developed at the summer programs. They also can send e-mail.

In the four years since the debut of CIBTnet, teachers have logged 4,505 hours in 31,091 phone calls. Dr. Bruns commented that more phone lines had to be installed and calls limited to 20 minutes but noted that such a problem was worth having.

Dr. Bruns said he believes that CIBTnet has succeeded where other networks have not because the people who use it know each other. They meet at the summer program and then get together with other program alumni twice a year at Cornell for one-day seminars. Teachers use CIBTnet to share their modifications of laboratory procedures.



Dr. Peter Bruns of Cornell University responds to a question on the Cornell Institute for Biology Teachers, which provides computer equipment and access to a science information network for rural teachers.

College of the Holy Cross

Dr. Vellaccio began his presentation with a digitized message that he prepared on compact disk to emphasize the ease of using the technology. "This is the first tool since the printing press that is changing how we go about teaching and learning," he said.

The College of the Holy Cross is beginning to use computer-based teaching materials in its partnership with the public school system in Worcester, Massachusetts. Worcester has 49 public schools with 1,800 teachers and 25,200 students. Forty-two percent of those are minority students, and 22 percent are in special education classes. Fifty percent come from low-income families.

The cornerstone of the HHMI funding partnership is a program of year-long sabbaticals for high school math and science teachers, during which they learn to integrate multimedia materials into their teaching. The program shows teachers how to use the technology and develop materials that provide self-paced learning for their high school students.

Another goal of the program is to integrate World Wide Web resources into the teachers' library of materials. The program will provide a home page on the World Wide Web that links teachers to other relevant parts of the information highway, such as Swarthmore College's Ask Dr. Math.

During the summer, the college runs workshops for math and science teachers that stress the role of computers in teaching. Other outreach programs that include a focus on educational and communication technologies are aimed at elementary school teachers and middle school students.

Washington State University

Washington State University's biology department has a history of working with high school and middle school teachers throughout Washington. Teachers are brought in for one- to two-week hands-on workshops.

In response to teachers' requests for access to resources, the biology department began an equipment loan program that includes fast plant experiments, spectrophotometers, and a skeleton. Last fall, 70 schools signed up for the equipment.

In response to requests for increased communication, three years ago Dr. Paznokas created an electronic bulletin board, state-of-the-art technology at the time. Teachers accessed the bulletin board through an 800 number, but they needed to purchase their own computers. There was an initial surge of activity when 100 teachers signed on, but only about 15 teachers used it regularly.

With the new technology offered by the World Wide Web, the situation is changing. A home page is being developed as an alternative to the electronic bulletin board. Teachers will be able to use e-mail and schedule equipment loans directly.

Dr. Paznokas is setting up the Virtual Science and Math Fair on the biology department's home page. Because of pending legislation on the establishment of a state technology infrastructure, Dr. Paznokas foresees the day when everyone in the state of Washington will have access to educational programs that now can be obtained only by attending classes on campus.

Access Excellence/ Genentech, Inc.

Five years ago, Genentech, a biotechnology company in South San Francisco, put $10 million into a project to connect high school biology teachers around the United States and to stimulate use of new technology in developing computer-based educational materials.

The core of the project is the Access Excellence Fellowship Program, which is coordinated with the National Science Teachers Association. Every year, highly motivated high school biology teachers are selected as Access Excellence Fellows. Each teacher is given a Powerbook computer and a subscription to America Online. Teachers attend a five-day training workshop in San Francisco to learn how to use the computers and the network and to begin collaborating with scientists, mentors, and each other to develop online projects.

The other element of Access Excellence is an open forum on America Online and the World Wide Web <http://www.gene.com/ae/>. The forum allows teachers and scientists to exchange information about teaching, research, and new developments in the biological sciences. Teachers can pose questions to each other and to scientists and can conduct online research projects with their students.

Features of the forum include a new topic every month; an activities exchange for educational modules used in the classroom; stand-alone scientific information used for research; an in-depth look at biotechnology; a guide to biotechnology careers; a news feature put together by a science journalist; a resources center; and courses, weekly updates on television and radio science programs, and short, entertaining facts that science teachers can use to spark up their presentations.

Discussion

Financial and Human Resources for Computer Networks. In response to questions about how the networks described by the panelists are funded, Dr.

Mr. Geoffrey Teeter, Access Excellence of Genentech, Inc., and Dr. Frank Vellaccio, College of the Holy Cross, look on as Dr. John Paznokas, Washington State University, describes how technology, such as the Internet, can empower teachers by giving them access to each other and to scientific information.

Paznokas explained that a half-time employee operates Washington State University's computer bulletin board. Dr. Bruns said that at Cornell two full-time people are employed to operate the equipment-lending library and a half-time employee operates the network.

Dr. Bernard White, Iowa State University, asked how institutions could be persuaded to continue supporting such programs when external funding comes to an end. Mr. Teeter replied that Access Excellence encourages its fellows to make presentations about the program at their schools. "If the teachers can prove a need for this type of education, then the schools will adopt it," he said.

Dr. Paznokas explained how his program encourages high school teachers to use existing local resources to obtain access to the technology they need to conduct experiments. "For water-quality testing, we encourage them to go to local public utility districts, which have an electrophoresis laboratory," he said. "Elementary, middle, and high school teachers are writing little grants to service groups and buying equipment."

Networks Beget Networks. Cornell University is finding that the high school teachers participating in CIBTnet are becoming a good resource to train middle school teachers, Dr. Bruns said. The network is also helping to educate Cornell students in the reality of teaching in poor urban schools. "Ten Cornell minority students spent a week teaching in an urban high school where one of our network's high school teachers works."

Interactions between universities and public schools must be jointly planned and developed, said Dr. Paznokas. At his institution, faculty members work with an advisory group from the state science teachers association.

Group 2: Responding to Students' Learning Styles

Beloit College □ John R. Jungck, Ph.D., Moderator
Spelman College □ Pamela J. Gunter-Smith, Ph.D.
University of Oregon □ Daniel Udovic, Ph.D.

Beloit College

The BioQUEST Curriculum Consortium, based at Beloit College, has been promoting a philosophy of science education for 10 years. Dr. Jungck said that this philosophy rests on students posing questions, pursuing problems arising from those questions, and persuading peers of the value of their solutions. BioQUEST has released over 40 software modules designed to help students and faculty put this philosophy into practice and has been running workshops for faculty members at different colleges and universities.

Collaborative learning environments have been established in many classrooms and laboratories that use BioQUEST modules, reaching students of different backgrounds, talents, and learning styles. To illustrate, Dr. Jungck presented a videotape of student work at four colleges and universities, showing how different science departments are using BioQUEST materials and the collaborative problem-solving method.

Millikin University in rural southern Illinois has a methods course that enables preservice elementary and secondary teachers to experience the research process. The program stresses model building, revision testing, and comparing field data with models. In the video, undergraduates preparing to be teachers demonstrated Environmental Decisionmaking, a BioQUEST module.

Students at Trinity University in Texas have used BioQUEST to create digital legacies of their experiences. Science students use digital video microscopy tools from BioQUEST to explore various areas of biology that are traditionally taught through descriptive lectures—anatomy, embryology, and cell biology. The students use PowerPoint presentation tools to record their research for other student investigators. The video showed students using computer imaging to analyze the development of an embryo.

At Drexel University, an inner-city institution in Philadelphia that emphasizes engineering and business, the Enhanced Biological Education program (EBE) uses 11 different BioQUEST modules. Students use computers in laboratory and classroom group investigations throughout a lower-division two-year general biology curriculum. Drexel is also experimenting with coordinating the first year of EBE classes with classes in mathematics and English.

Beloit College uses studio, workshop, and collaborative classroom approaches, with students as teaching assistants. In

Drs. John Jungck, Beloit College, and Pamela Gunter-Smith, Spelman College, discuss ways in which educational technology can attract and retain students in the sciences.

the video, undergraduates in a genetics course used several BioQUEST modules and two dozen computer applications. Each week one group presents a poster on a hypothesis it has been investigating and the results obtained.

Spelman College

Dr. Gunter-Smith told how Spelman has been reforming its science curriculum. One of the main goals of the reform, now in its fourth year, has been to have students learn science by actually doing science. College faculty members and administrators had become concerned that their approach to undergraduate science education was somehow turning students away from science.

In their search for solutions, they thought back to some of the things that had excited them about science when they first entered the field and agreed that excitement did not come from sitting in a lecture hall. They decided to make changes in undergraduate science education that were geared to recreating the thrill of discovery.

First, a new pedagogy based on Karplus's *Learning Cycle* model was introduced. This pedagogy stresses a problem-solving/learning experience approach that proceeds through three phases: discovery, explanation, and application. Teaching laboratories formerly were too cookbook-like (i.e., too much stress was put on students achieving the expected result) to retain students' interest and tended to reward students who fit a certain mold.

In the revised laboratories students are encouraged to do research that parallels that done by scientists. For example, students work in small groups on a project to identify the general characteristics of enzyme activity. They are not told what the outcome of the experiment should be. Instead, they develop hypotheses, test them for accuracy, and adjust the hypotheses on the basis of their findings. Then they apply these hypotheses to other situations.

Second, cooperative learning was stressed. Instead of taking notes in large lecture halls, students worked on problems in small groups.

The third step was to increase the number of required laboratories and decrease the amount of time spent in lectures.

Fourth, the college made a major commitment to integrating advanced technology into the laboratory setting to complement, not replace, wet laboratories. Computer workstations were installed for graphing data, setting up spreadsheets, and running other applications used in science. Finally, the use of live specimens was emphasized in an attempt to recapture the excitement of science and to give students a firmer idea of how organisms behave and respond to stimuli.

In assessing the effect of the changes so far, the college is trying to find ways to evaluate whether students have acquired new skills as a result of the reforms. Dr. Gunter-Smith said that she believes the new approach captures and expands student interest in science and helps students actively participate in their own learning. They are focusing on content, and their learning skills have developed.

The new approach requires more preparation time by instructors, and some faculty members have been reluctant to change their approach to science teaching. There is also some evidence that science courses are covering less material since the reforms were put in place. Dr. Gunter-Smith said that a new evaluation tool is needed before any conclusion can be reached on whether the reform is doing a better job of turning out a new generation of scientists. She stressed that the reform is a continuing process.

University of Oregon

One way to address the needs of students with diverse learning styles, according to Dr. Udovic,* is to involve students actively in rich and diverse, yet logically structured, learning experiences. Activities that allow students to experience scientific phenomena for themselves, construct their own explanations and models for phenomena, and test their developing explanations appeal to a wide range of student learning styles.

Rather than using technology to enhance traditional teaching methods, the university's approach is to fully engage students whose learning styles are not compatible with traditional science pedagogy by placing the

* Dr. Udovic was unable to attend the meeting. This summary is based on an abstract he submitted.

technology in their hands. In addition to using resources available from other sources, the university's HHMI-funded Biology Software Lab is developing its own technological tools. Efforts are focused in three areas.

First, general simulation tools with easy-to-manipulate graphic interfaces are being developed to enable introductory students to construct models of important phenomena and conduct investigations that would otherwise be impossible in a classroom setting. For example, students model the dynamics of age-structured populations by manipulating population-age pyramids and graphs of age-specific fertility and mortality. Using data available on the Internet or from the scientific literature, students can model population dynamics for a variety of species, including humans.

Second, data-acquisition tools are being developed to simplify data collection and allow students to perform multiple experiments and analyze large sets of data in the time they might otherwise spend learning to set up a new piece of equipment. As with simulations, the technology gives students more opportunities to make observations and construct accurate conceptions.

Third, the university is supporting the incorporation of Internet tools into classroom activities, including access to informational databases, enhanced communication among faculty and students, and student development of Internet resources. For example, over 100 students taking introductory biology for science majors collaborated on developing World Wide Web pages as part of their term project.

Discussion

Workshop Approach to Science Teaching. Dr. Jungck noted that the teaching approaches introduced at the University of Oregon are based on the workshop approach to science teaching developed by Dr. Priscilla Laws of Dickinson College. The workshop approach emphasizes hands-on learning and places students in charge of their own learning. The University of Oregon program was one of the first to apply this approach in a laboratory context, Dr. Jungck said.

Course Content: Is Less More? Many participants questioned whether programs such as the ones described provide students with as much content as do traditional science courses. Dr. Paula Dehn, Canisius College, said that her institution has developed an approach similar to those described by the panelists and introduced it throughout the entire freshman and sophomore science curriculum. The college has found that although students do laboratory research by their senior year, they cover less content than previously. Another participant said that students in innovative programs may be at a disadvantage when taking the standardized tests required for admission to graduate school.

Dr. Gunter-Smith said that Spelman College has tried to address the issue of course content in part by removing redundancy among its courses. Although less material may be covered in any one course, she said, the college's overall program covers all the necessary content. Dr. Jungck cited extensive research demonstrating that "less [content] is more": students enrolled in innovative programs develop a depth of knowledge and an ability to retain that knowledge unmatched in the traditional approach to science education.

Dr. T. J. Mueller, Harvey Mudd College, said that his students seem to be better motivated and to internalize more content than students in traditional courses. "The difference is students get excited," he said. He added that innovative approaches de-emphasize lecturing by professors and encourage students to use their own initiative to acquire knowledge. Dr. Michael Gaines, University of Miami, said that the goal of education should be to get students to think; "less is more" only if it provides students with the concepts needed to deal with the world around them.

Assessment. Dr. Jungck said that several attempts are under way to develop new measures to assess technology-based undergraduate science courses and programs. At Drexel University, a survey researcher and an ethnographer are analyzing student performance, using available data on such questions as whether students complete science courses, take additional science courses, and are more likely to participate in other science-related activities. Dr. Jungck noted that one researcher found that Beloit College nonscience majors developed more positive attitudes to science after taking innovative courses.

A growing body of research on problem-solving abilities makes it possible to examine changes in these abilities after students have participated in an innovative science program, Dr. Jungck said. He added that the BioQUEST curriculum consortium is working closely with researchers who are collecting this kind of data.

Dr. Martha Crunkleton, Bates College, said that one measure of the success of the innovative biology program at Bates is that biology is now the college's most popular major, whereas four years ago it ranked sixth. In addition, faculty efforts have been recognized by Project Kaleidoscope.

Cost of Innovation. Workshop participants discussed whether new approaches to science education require more investment in time and resources than traditional approaches. One participant argued that hands-on laboratories are more costly. Dr. Jungck responded that in his experience innovative laboratories are a good investment.

Most participants agreed that hands-on, student-centered laboratories require a greater time commitment than traditional laboratories. Some said that this can present a problem for students who work part-time. Several participants suggested ways to make it easier for students to do their laboratory work. Dr. Lillian Tong, University of Wisconsin–Madison, said that her program has developed hands-on activities that allow students to take materials back to their dorm rooms. Dr. Paul Hertz, Barnard College, described an innovative approach to teaching ecology that overcomes some of the limitations of the college's Manhattan location.

Utility of Tracking Science and Nonscience Majors. Dr. Don Dennis, University of Delaware, asked if it would be useful to have two science education tracks: one for future scientists that would emphasize hands-on science and hypothesis generation; the other for nonscience majors that would take a more traditional approach to science education.

Dr. Jungck said that Beloit College does not distinguish between future research scientists and other students. He argued that it is important for all citizens to have a deeper understanding of and appreciation for science. Dr. Gunter-Smith added that Spelman College believes it is important to produce knowledgeable consumers of science as well as scientists. Nonscientists should be well informed, she said, because they will have a say in apportioning science resources.

Conclusion. Dr. Jungck concluded by encouraging those committed to innovation in science education to form a community and to share insights regularly in a public forum. He also urged attendees to continue their discussions outside the meeting. "We owe it to our colleagues," he said, "to learn from one another and review one another's work."

Group 3: Bringing Science Closer to Students

Reed College □ Stephen Arch, Ph.D., Moderator
Texas Tech University □ Richard L. Blanton, Ph.D.
University of North Dakota □ Albert J. Fivizzani, Ph.D.
National Center for Supercomputing Applications □ Scott Lathrop, Resource

In moderating his panel session, Dr. Stephen Arch of Reed College remarks on the importance of maintaining a balance in undergraduate science education between computer-simulated laboratories and hands-on experimentation in wet laboratories.

Reed College

Over the past five years, the Reed biology faculty has addressed what it perceives to be a stumbling block for many students with career interests in science: poor quantitative skills. Quantitative techniques were introduced broadly across the curriculum to enrich and inform the processes of designing experiments, analyzing data, presenting results graphically, and interpreting experimental outcomes. According to Dr. Arch, this quantitative and computational initiative has dramatically influenced the curriculum.

Nearly every introductory biology laboratory now has a computational component for either data analysis or simulation. All biology majors must take a sophomore-level course designed to systematize their exposure to the scientific paradigm and to ensure that they enter the upper division with a common grounding in both the philosophy and the computational methodologies of biology. Every upper division course has incorporated a substantial computational component, many with newly and locally developed simulation models.

The Science Center, a drop-in combination tutorial, problem-solving session, and workshop to enhance network skills, is an adjunct to the computer classroom and an outreach effort to biology majors and nonmajors who are encountering difficulties in introductory science courses. In addition, all biology majors have access to specifically developed curricular software and statistical and graphical packages that reside on the Department of Biology network file server.

The efforts to bring information technology to undergraduates have been highly successful, and there have been measurable benefits to the curriculum. Dr. Arch noted, however, that a computer program cannot replicate the feel, smell, and experience of being in an actual laboratory, nor can educational technology anticipate and simulate the vast spectrum of problems that creative undergraduates encounter as they learn their way around a laboratory. At Reed College zeal and enthusiasm for the advantages of educational technology drive neither the curriculum nor the educational objectives.

Texas Tech University

Efforts at Texas Tech University have been primarily focused on providing workshops and other support to enable teachers to bring science closer to their students. Teachers and students in rural school districts have needs that cannot be effectively met solely through the traditional means of summer workshops and seminars on teacher in-service training days.

Among the challenges are the great distances, which render field trips impractical and travel to in-service workshops difficult; the absence of qualified substitute teachers in small towns, which prevents teachers from participating in meetings and workshops during the school year; the situation in many small rural school districts of having one science teacher for kindergarten through 12th grade; and the isolation of those teachers from other science and mathematics teachers.

Attempts are being made to address these challenges by using satellite and other distance-education technologies. The strategies being followed include determining what networks and capabilities already exist and how they can be used for precollege science education. Partnerships with other organizations involved in distance education avoid duplication of effort, take advantage of other expertise, and increase leverage of available funds.

The Texas Tech University project involves the Education Service Center responsible for supporting the schools in the region, a distance-education cooperative involving all of the colleges of education and numerous school districts in the region, and HealthNet, a rural health services network centered at the Texas Tech University Health Sciences Center.

Effective distance education and in-service training will require special efforts to train presenters and to design programs to effectively address the needs of the teachers in the region. Being in a position to take advantage of changes in state and national telecommunications regulations will also affect the program's success.

University of North Dakota

Geographical separation is a major obstacle inhibiting interaction between the University of North Dakota and community colleges that provide initial training for undergraduate students in the biological sciences. The North Dakota University System, recognizing this impediment, has committed itself to developing outreach education via an interactive video network.

The community colleges on Indian reservations, previously administered by tribal councils, originally were not part of the network. Now classrooms at all tribal community and technical colleges have been connected to the network, linking them with the university and the North Dakota Higher Education Network. Students can take undergraduate courses in science and mathematics via the network to prepare for enrollment in advanced courses at the university.

The university will offer up to two undergraduate biology or other science courses per semester on the network to students at all five tribal community colleges. Courses are primarily focused on natural resource management, an area of immediate relevance and application on Indian reservations. In addition, there is a plan to offer academic courses from the School of Nursing and the Center for Teaching and Learning.

Through such offerings students will be able to pursue degrees in fisheries and wildlife management or environmental geology and technology. Establishment of network linkages among the community colleges will also allow these faculty members to share their expertise with other campuses. Thus, courses such as Ethnobotany and the Role of Science in Tribal Cultures could be offered across the tribal college system.

National Center for Supercomputing Applications

The cost of laptop computers is projected to drop below $200. Mr. Lathrop predicted that undergraduates will use laptops to plug into a network from which they can record and digitize lectures and access libraries and online curriculum and text materials. Such resources will serve as learning tools for students from kindergarten through college.

Educational technology will change the face of teaching, Mr. Lathrop said. Teaching may be synchronous across the Internet, allowing remote-control presentations and two-way communication. The asynchronous mode of teaching, however, is likely to dominate. Collaborative software will be developed and a virtual university will be available online, challenging traditional education from kindergarten through graduate school.

Learning tools will include an integrated environment for faculty members, a fully networked environment for students, online access to resource materials, remote participation, consultations across large distances, and chat groups among different constituencies.

The National Center for Supercomputing Applications (NCSA) Telnet includes the NCSA Datascope, a visualization tool; NCSA Collage, for a collaborative environment; and NCSA Mosaic, to bring access to resources. The focus of the program is to build a bridge between the laboratory and the classroom. NCSA resources comprise the Illinois Learning Mosaic, Resource for Science Education, and Simulations. Evaluations of programs are conducted at colleges of commerce and engineering, elementary and secondary schools, and institutions of higher learning participating in partnerships with elementary and secondary schools.

Discussion

The Electronic Classroom. Lectures, but not textbook materials, are now available on the World Wide Web, noted Dr. Robert Krug, Rutgers University. Although CD-ROM is also being prepared for use on the Web, it is likely to become obsolete, as will many kinds of software. In their place will be virtual reality and possible pay-for-use software on the Web.

Challenges Presented by Classroom Broadcasts. Lecturers' on-camera presence may be quite different from their in-classroom personas, noted Dr. Thomas Lonergan, University of New Orleans. Some may be uncomfortable with the restrictions imposed by the broadcast medium. Mathematicians, for example, like to inscribe theorems and examples over a large expanse of blackboard, which does not work well on camera. Students' exposure to commercial broadcasting creates a level of expectation that may force institutions to use consultants to improve the professional appearance of their products. Dr. George Cain, University of Iowa, has found that some students prefer taped lectures to live ones.

Faculty Role in Promoting the Use of Technology in Education. Participants agreed that the role of faculty in harnessing technology to education is critical. One strategy that has been successful is to involve faculty members who are committed to access by minority students. Just as scholarship is shared among faculty members, so too should progress in the use of information technology for teaching be shared and critiqued. However, the extent to which teaching and technology-based activities should be considered for tenure decisions remains controversial. Dr. Sondra Lazarowitz, University of Illinois at Urbana-Champaign, observed that whereas younger faculty members may have the energy and skills to take the lead in applying technology to education,

Drs. Larry Blanton of Texas Tech University and Albert Fivizzani of the University of North Dakota, and Mr. Scott Lathrop of the National Center for Supercomputing Applications respond to questions from program directors on how long-distance learning can be used to reach a wider range of students.

they are more at risk from adverse decisions by tenured faculty.

Faculty members who strongly support traditional educational approaches may be resistant to change, said Dr. Fivizzani. Institutional administrators may lack suitable means for evaluating the innovative teaching efforts of junior faculty. Dr. Prentiss Cox, Mississippi College, argued that research is frequently judged by quantity rather than quality of publications. He added that it is usually well known on campuses who the better teachers are, even if teaching evaluations are hard to quantify.

Another factor that may mitigate against institutions' ability to reward outstanding teaching that incorporates novel technologies is the inability to recover indirect costs, as can be done with research grants. Removing these inequities will require altering the reward systems at the national level, noted Dr. David Bynum, State University of New York at Stony Brook. Other attendees pointed out that colleges where teaching is a primary focus have developed evaluation methods such as surveying alumni. Assessing teaching effectiveness has been a primary objective of the American Association of Higher Education, which has been involved in a review of teaching at research universities as well as in the development of effective teaching criteria.

Cost of Investing in Telecommunications. Dr. Blanton noted that although the cost of receiving transmissions is relatively modest, the costs of installing and maintaining communications lines may be significant and institutions often lack the money to meet these costs. Dr. James Ryan, Hobart and William Smith Colleges, said that decisions on equipment purchases are further complicated by the rapid obsolescence characteristic of the telecommunications industry. Deregulation can lower costs by stimulating competition, but institutions are dependent on government taking the necessary action. Institutions also cannot control the distribution of telecommunications resources.

Redefining the Teaching Laboratory

The undergraduate teaching laboratory is being redefined as educators strive to create a learning environment that more closely resembles the actual process of scientific discovery. According to one program director, the science laboratory is becoming an arena for re-experiencing human curiosity.

Educational technology plays an important role in the new teaching laboratory. In Session II, presenters described institutional efforts to use educational technology to revitalize introductory biology and chemistry curricula and foster interdisciplinary teaching and initiatives to involve science faculty in the creation and adoption of new learning technologies.

Using interactive multimedia software, students can not only visualize scientific concepts in ways never before possible, but also familiarize themselves with laboratory instruments and design and perform virtual experiments. Institutional strategies to facilitate student access to such software include making it available in campus computer laboratories and over computer networks and the World Wide Web. Meeting participants noted that institutions could develop better strategies for providing student access to technology if they had more information about the level of computer literacy among entering undergraduates.

Although an increasing number of institutions are finding that computer simulations add a valuable dimension to undergraduate science teaching, educators generally feel that such tools should not replace hands-on laboratory experience. Two speakers emphasized that at their institutions electronic simulations of scientific processes are used to enhance or supplement experience in the wet laboratory.

The introduction of new technology and new teaching approaches can place new demands on faculty members that may not be entirely welcome, at least initially. Some participants commented that interdisciplinary teaching approaches had met with some resistance among faculty at their institutions. One speaker said that instructors need courage and dedication to work outside their discipline. A variety of strategies were described that may be useful to institutions wishing to encourage faculty to become actively involved in developing new technology-based teaching approaches.

Redefining the Teaching Laboratory

Carnegie Mellon University ☐ Susan A. Henry, Ph.D., Moderator
Bryn Mawr College ☐ Paul Grobstein, Ph.D.
University of California–San Diego ☐ Gabriele Wienhausen, Ph.D.

Carnegie Mellon University

Dr. Henry gave a multimedia presentation complete with a video, describing the array of interactive multimedia tools developed and used by Carnegie Mellon University in classrooms and research laboratories, and two short digitized video clips of remarks by faculty members. She began by stressing that the university is well equipped with technology resources, strong fine arts resources, and special strengths in data storage, retrieval, and networking.

The Mellon College of Science has created two new curricula: computational biology and computational chemistry. In the first video clip, Dr. David Yaron explained that computational technologies can change not only the way people do chemistry, but how they think about chemistry. He demonstrated how students in a computer laboratory can manipulate a computer image of a DNA backbone to gain insights into its structure.

Dr. Robert Murphy provided details about computational biology in the second video clip. Topics covered in one of the new courses, Introduction to Computational Biology, include biological modeling and simulation, graphics and statistics, and biological imaging. Course work includes homework assignments that use software for these applications. In addition, students are using the university's high-technology laboratory facilities to develop ways to use computers to solve problems in biology. He demonstrated how students obtain protein structure files from sites on the Internet and then use the files in their laboratory work.

Dr. Henry described the university's central technology fa-

Dr. Susan Henry, Carnegie Mellon University, leads a plenary discussion on how interactive computer technology has provided students with tools previously available to research scientists and allowed faculty members to redefine their roles as science teachers.

cility, the Computer Training Center. The center includes 24 Silicon Graphics workstations and is the core teaching facility for computational biology and chemistry. She pointed out that the College of Science is expanding the science experience for undergraduates by using the World Wide Web and e-mail for research resources, assignments, class notes, and even counseling by advisers.

The university is also developing a new generation of integrated teaching laboratories focused on cell and developmental biology. These laboratories will enable undergraduate students working in a single facility to combine computational methods with advanced experimental techniques and equipment normally available only to research scientists.

Dr. Henry said that the real issue is whether computer laboratories are replacements for wet laboratories. "We believe they are enhancements, not a substitute for the experimental side of science," she said.

She concluded by noting that computer technology requires a heavy investment of resources. To ensure that the teaching laboratories are used as effectively as possible, they have been designed to be used during the summer as part of the university's outreach program for precollege educators.

Bryn Mawr College

Dr. Grobstein began his presentation by noting that Bryn Mawr College is rethinking the objectives of teaching laboratories and experimenting with corresponding modifications of traditional teaching laboratory practices. He thinks this reform can be undertaken with or without computers.

To illustrate what Bryn Mawr is doing with teaching laboratories, Dr. Grobstein focused on Biology 101, "a course predicated on the fundamental activity of science itself." Using display software and the Internet, Dr. Grobstein connected to Bryn Mawr's Serendip World Wide Web site, a resource on the brain and behavior that combines brain research, computer science, and education: <http://serendip.brynmawr.edu>. Dr. Grobstein then linked to the course description of Biology 101, pointing out that it informed students that the course placed more responsibility on them for their own education than did traditional science courses.

In describing the laboratory associated with Biology 101, Dr. Grobstein said that in several different courses, Bryn Mawr has moved away from the traditional notion of the laboratory as a means to transmit a particular body of information, teach a certain set of techniques, or create a particular set of experiences.

Dr. Paul Grobstein of Bryn Mawr College gives examples of student hypotheses tested on Serendip, a World Wide Web site on the brain and behavior that has been integrated into the College's curriculum.

Instead, the college is attempting to create an environment where students will learn by generating fundamental questions and addressing them with available materials. Such laboratories encourage students to explore fewer subjects but in greater depth and with much more freedom to define the problems and the methods of analysis and interpretation.

Dr. Grobstein used as an example a laboratory exercise from Biology 101 that helps students understand the brain's critical role in creating one's picture of the world. The exercise began with the fundamental question: how sure are you that what you see is reality? Students knew that certain areas of the eye's surface lack photoreceptors. By holding up to one eye a chart containing basic patterns of dots and lines and then shifting the position of the chart, students were able to discover that under certain circumstances the brain creates a visual image where, in fact, there is none. Students then designed their own charts with different shapes and colors and worked with them to discover more about the circumstances under which the brain creates false images.

The key to the laboratory exercise, Dr. Grobstein said, is that students used a simple set of observations in an open-ended process to discover important fundamental principles.

Creating a new kind of laboratory and a new approach to science education requires that instructors think about what kinds of observations speak immediately to the needs of students, yield general principles, and have an open-ended character. Instructors must be flexible and have a breadth of background as well as a willingness to treat students as participants in a shared inquiry. Dr. Grobstein said that faculty members and students reacted to this new approach to teaching laboratories with some enthusiasm, some uncertainty, and some discomfort.

Some faculty members were uncertain whether they could teach the new laboratory approach. Others were uncertain that such an approach would prepare students for later course work or for work in real-life laboratories. Students also had some reluctance. Some were not sure they would be able to ask questions that would get to important issues; others wanted clearer objectives and were frustrated when they did not get complete answers.

Common to all these concerns, Dr. Grobstein said, is a view that science education is a hierarchy of information acquisition and that the science laboratory is the most rigorous and advanced form of science education. Bryn Mawr, by contrast, wants to make the science laboratory an arena for re-experiencing human curiosity, one that is not distinguished from science education or liberal arts education generally. He added that blurring the walls of the teaching laboratory in this way helps and is helped by related efforts to create a more open and engaging science curriculum.

University of California–San Diego

Dr. Wienhausen's presentation focused on a software tool developed and used by the University of California–San Diego that helps students visualize submicroscopic events and understand the theory and methodological principles behind laboratory procedures and equipment.

Because students have a great deal of difficulty understanding events they cannot visualize and are often intimidated by laboratory equipment, Dr. Wienhausen and her colleagues developed an interactive virtual laboratory manual. The goal is for students to enter the wet laboratory with a better understanding of laboratory concepts and techniques so that they progress quickly from learning techniques to investigating basic questions.

The manual has three modules: an experiment module, an equipment module, and a calculation module. The experiment module allows students to perform the experiment on the screen. Students are led through protocol development, introduced to literature searching, and given access to as much background information as they want. The manual helps students to perform critical experimental steps on the computer screen, with animated images illustrating how procedural steps are actually accomplished. By providing thought-provoking questions, the software challenges students to probe more deeply.

The equipment module develops the theory and methodological principles behind a method. A virtual instrument allows the students to practice while observing what happens inside the "black box." Dr. Wienhausen had the software display the preparation of a plant homogenate. Animated illustrations showed why it is necessary to chop the plant finely to release cellular structures. She illustrated a virtual spectrometer on screen and showed how each part functioned.

Dr. Wienhausen said that the university has had the most difficulty with the calculations module, which allows students to practice the calculations required for laboratory work. The module is undergoing further development.

Dr. Wienhausen stressed that the virtual manual allows students to decide how deeply they want to go into the modules and to set their own pace. She reported that in general students are enthusiastic about the manual and want to see additional modules developed. In addition, the modules function as a knowledge equalizer because all students have access to the same background information.

Dr. Gabriele Wienhausen discusses the interactive laboratory manual developed in her laboratory at the University of California–San Diego that allows students to visualize microscopic events in experiments or observe what occurs inside the "black box" of scientific instrumentation.

Discussion

Impact of Technology on Students and Faculty. Dr. Wienhausen was asked several questions about the application of the interactive manual to laboratory teaching. She said that students who use the manual work much more effectively in the wet laboratory than those who do not. Many students use the computer laboratory for about 15 minutes before entering the wet laboratory and frequently come back for longer sessions.

Since beginning work on the manual in 1991, Dr. Wienhausen said, her team has completed four modules. In the hope of speeding further development, a full-time graphic artist and computer programmer are now working on the project.

Faculty members who worked on the software found that the experience changed their approach to teaching, Dr. Wienhausen added, because they were forced to think very clearly and logically about experiments, equipment, and other issues. She said the team was making efforts to incorporate student input in the development of future modules.

Several attendees asked Dr. Grobstein how the Serendip program could be used to teach students to develop hypotheses. He replied by giving examples of some of the hypotheses presented and tested by students, such as "The brain will only add white to the image it creates," and "The brain will only add uniformities." He added that some students who had been successful in previous science courses and were pursuing careers in science had to overcome some initial difficulties with the new approach.

Dr. Peter Bruns, Cornell University, asked if the new emphasis on multimedia and other computer applications in laboratory work might result in students losing critical skills such as how to keep a scientific notebook and otherwise communicate in writing. Dr. Henry replied that at Carnegie Mellon a strong curriculum-wide emphasis continues to be placed on writing, especially in science courses. Dr. Wienhausen noted that her students are still required to keep laboratory notebooks.

Assessment of Computer Laboratories. Several questions focused on how to assess the effectiveness of these new approaches to laboratories, given the large commitment of resources that they require. Dr. Henry said that Carnegie Mellon uses its standard assessment tools to evaluate advanced courses that use the newer computational approaches. She added that the best way to assess the effectiveness of the new techniques remains an open question. Other program directors noted the difficulty of obtaining hard data on student performance in laboratory courses but said that subjective data on student interest and attitudes are encouraging.

Group 1: Revitalizing Introductory Biology and Chemistry

California State University–Los Angeles □ Alan Muchlinski, Ph.D., Moderator
Iowa State University □ Bernard J. White, Ph.D.
Vanderbilt University □ James V. Staros, Ph.D.
University of Chicago □ John A. Kruper, Resource

California State University–Los Angeles

For many students attending California State University–Los Angeles, the freshman biology course is the first biology course they have ever taken. The Department of Biology used to offer review sessions after laboratory classes, but most students had jobs and were unable to attend. The main complaint of the many who dropped out or did poorly was that there was too much information to absorb and not enough explanation of the material.

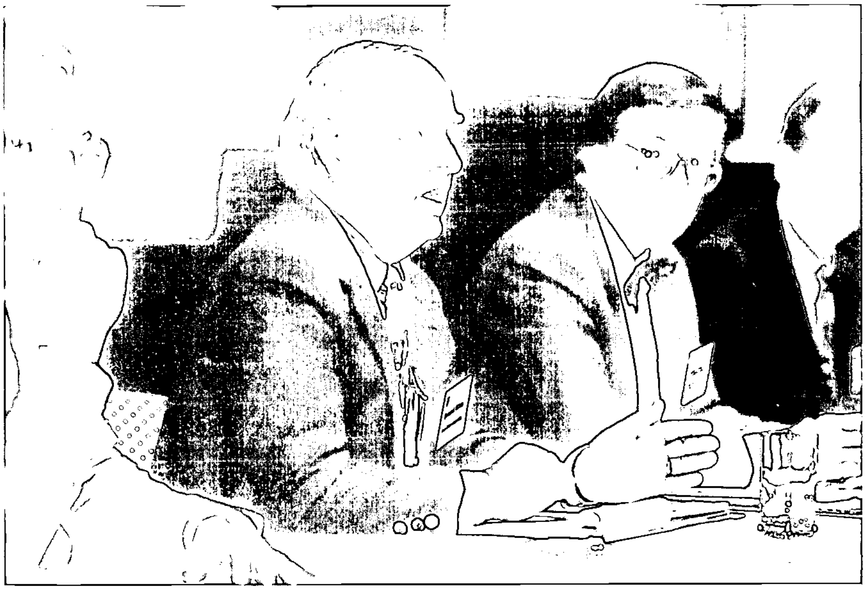
To remedy the situation, the departments of biology and microbiology established a computer-videodisk technology laboratory for use as an open-access study laboratory by students in many science courses, including three basic biology courses and three upper-division courses. The laboratory houses 11 videodisk workstations, where students work in groups of two to four. Two additional workstations on portable carts are used in teaching laboratories and lecture rooms.

Dr. Muchlinski said that the computer laboratory has allowed students greater access to course material and has improved comprehension. Students spend the first 45 minutes of certain laboratory exercises using the appropriate Hypercard stacks and associated videodisk images as an introduction to the laboratory material. Hypercard stacks are interactive software in which text and graphics are combined with videodisk images. After viewing the images on Hypercard, Dr. Muchlinski said, students know what to look for under the microscope and can move more quickly through the material.

According to Dr. Muchlinski, the students' reaction has been positive: 96 percent used the laboratory outside normal teaching hours; more than 50 percent rated it as very helpful; and more than 40 percent said that it was helpful.

Iowa State University

In 1991 Iowa State University redesigned its core biology curriculum, incorporating a commitment to the use of technology in instruction. The university put in place 100 student laboratories equipped with 600 Macintosh and 800 DOS-based computers and a biology microcomputing facility that has 75 computers and is open and staffed 60 hours a week. All computers are connected to DARWIN, a biology file server that contains 7,000 slide images,



Drs. Alan Muchlinski of California State University–Los Angeles, Bernard White of Iowa State University, and James Staros of Vanderbilt University, and John Kruper of the University of Chicago discuss strategies for using and assessing educational technology in introductory science courses and laboratories.

videos, and 40 animations of biological concepts. DARWIN is available to students 24 hours a day.

To entice science faculty into teaching one of the four core courses, which required the incorporation of DARWIN's resources, the university purchased a dozen Powerbook computers equipped with PowerPoint software. The computers were loaned to faculty members for the development of instructional materials for the core courses. A full-time computer technologist was hired to run training workshops for faculty.

Dr. White said that the faculty adapted to the technology in small steps. First, they learned how to convert their lectures into colorful words and simple graphics. Once they were comfortable with processing words, they learned how to import images from DARWIN into their lectures. Some faculty members have incorporated off-the-shelf simulations or developed simulation software for their courses.

The lectures for the core courses, including visuals, are stored in DARWIN, which students can access over the campus computer network. A preliminary assessment showed that 78 percent of the students who took the core biology courses said that the integrated advanced technologies were helpful or very helpful to the lectures and for review.

The use of computers is incorporated into laboratories to provide graphing programs for data analysis, to display simulations that model complex phenomena, and to access the Internet. According to Dr. White, students feel that computer presentations add interest to classes, aid their note-taking, and are helpful for lecture review. Faculty members are more eager to teach in the introductory courses and report that "technology causes one to rethink the course."

Vanderbilt University

Vanderbilt University developed a joint entry-level course for biology and molecular biology majors. This course is taken by 400 students during the second half of their freshman year and the first half of their sophomore year.

To provide a catalytic environment for the rapid development of students at the introductory level of biological sciences, the university also built a state-of-the-art teaching facility that combines a conventional wet laboratory with a networked workstation environment. The facility can accommodate 60 students at 30 workstations. The instructor has two computers, one of which controls all the computers. The software comprises interactive teaching and analytical devices.

Dr. Staros noted that the computer simulations do not replace the wet laboratory. Rather, they prepare students for the wet laboratory, giving an idea of how to use the equipment and what techniques to master. "We try to make it as interesting as possible," he said, for example, "by programming in sounds when they're turning things on and off."

The students use the laboratory to explore basic concepts in science and to take interactive quizzes. They use the computer to build a virtual laboratory manual. The system has a server on Vanderbilt's broadband network so that students can access it from their dorm rooms, and the laboratory is also open between class hours.

Extensive custom courseware has been written for use in the computer laboratory. The courseware includes didactic tutorials, simulations of experiments, and data analysis programs and is available over the campus network.

University of Chicago

After in-depth reviews of the undergraduate and medical school curricula, the Biological Sciences Division Office of Academic Computing (BSDAC) was formed in 1990 to increase the use of computer-based educational materials. A 250,000-square-foot Biological Sciences Learning Center was built to emphasize the interdependence of research, teaching, and patient care. One of the goals was to revitalize introductory biology.

BSDAC has 14 staff members, 4 of whom designed the software and now train other staff members to use it. The center serves faculty members and students, including nonscientists, advanced undergraduate biology majors, and medical students.

BSDAC has three goals: first, for people to use the network and not have to rely on computer laboratories; second, to encourage the use of simulation, which has resulted in the development by faculty members of three modules for the BioQUEST consortium; and third, to integrate the technology with the wet laboratory by using visualizing instruments to control instruments and log data.

One of the unique aspects of the computer engine is that the server is the database. Phoenicia is the Web-based academic information system developed to support teaching, research, and clinical care. Dr. Kruper noted that information is massively interlinked rather than stored in static files in multiple locations.

Phoenicia provides personalized online access to information resources that range from research and instructional materials to administrative resources, research and clinical information, and utilities. Designed as a true groupware application rather than a simple Web server of information files, Phoenicia provides a wide range of tools.

The Student Allele Database (SAD), developed in collaboration with the DNA Learning Center of Cold Spring Harbor Laboratory, is targeted at undergraduate introductory biology and advanced precollege classes. SAD develops an educational analogue of the human genome project that personalizes gene technology and provides unique learning opportunities for students.

For example, in a computer-controlled hands-on laboratory, a student produces a personal "DNA fingerprint" of a polymorphism on chromosome 8 (TPA 25). The resulting genotypes are uploaded to SAD, which also contains tools for students to investigate their own data, compare their data with that of divergent populations, and explore scientific and ethical issues surrounding the Human Genome Project.

Discussion

Encouraging Faculty Involvement. In response to a question by Dr. Albert Fivizzani, University of North Dakota, Dr. White said that at Iowa State University each faculty member who participated in developing computer-based educational materials received release time and a Macintosh Powerbook computer. One of them said it forced him to rethink how to teach the course.

Dr. Staros said that Vanderbilt bought computers for participating faculty. Finding faculty to teach the new courses had not been a problem, he said. By contrast, California State University–Los Angeles had no funds either to buy computers for faculty or to support faculty release time, said Dr. Muchlinski.

Student Response and Assessment. Dr. Gary Francois, Knox College, asked how the new approach had

Drs. Kathryn Vogel, University of New Mexico, Deborah Kaska, University of California–Santa Barbara, and Michelle Murphy, University of Notre Dame, comment on software presented during the educational technology demonstrations.

affected student performance. Dr. White said that Iowa State University is trying to develop an effective assessment tool. Anecdotal data suggest that "this is just another way of transmitting information and it works better with some [students] than with others," he added. Vanderbilt University conducts a detailed student evaluation at the end of every course, said Dr. Staros. Most students respond positively, but a few find the new technology intimidating.

Dr. Kathryn Vogel, University of New Mexico, asked if the availability of faculty members' lecture notes on the Internet had affected class attendance. Dr. White said he would be hesitant to draw a conclusion. Dr. Kruper related anecdotal information that seemed to show that attendance fell when teachers used class time only to read their lecture notes. "If they do a value-added presentation, attendance stays high throughout the term."

Dr. Vogel also wanted to know what effect the new technology was having on faculty-student relationships. Drs. Muchlinski and Staros agreed that the new technology encouraged interaction. "Students can reach me more quickly with e-mail," said Dr. Staros. "They don't have to wait for office hours."

Group 2: Fostering Interdisciplinary Teaching

New York University ☐ Lynne Kiorpes, Ph.D., Moderator
Harvey Mudd College ☐ T. J. Mueller, Ph.D.
University of Delaware ☐ Don Dennis, Ph.D.

New York University

New York University has created an undergraduate curriculum in neural science, a field that overlaps traditional scientific boundaries and thus is inherently interdisciplinary, Dr. Kiorpes said. Neural science's goal of understanding how the nervous system works interests scientists from diverse disciplines. In part, this is because scientists investigate many different aspects of the nervous system, including biophysics, cell chemistry, neuronal systems, behavioral physiology, and psychology.

Students majoring in neuroscience at the university take courses in the traditional disciplines of biology, psychology, chemistry, physics, mathematics, and computer science, as well as courses in neuroscience developed with HHMI funds. The neuroscience major builds on courses in other departments. The neuroscience curriculum includes Introduction to Neuroscience, a laboratory in Cellular and Molecular Neuroscience, a laboratory in Behavioral and Integrative Neuroscience, and a research tutorial.

The laboratory courses last for a year and teach neuroscience methodology. These courses depend heavily on interaction among faculty from different departments—especially physics, psychology, and chemistry—who develop lectures and laboratory sequences. Dr. Kiorpes noted that the new technology available in the laboratories attracts faculty members from various disciplines and gets them involved in the neuroscience curriculum.

The laboratories make heavy use of computational methods and databases. Computer laser disks are useful for teaching neural anatomy, and computers allow students to do virtual experiments, such as testing the effects of a chemical on a squid axon. Students also do a lot of work in hands-on wet laboratories. Dr. Kiorpes explained that nearly all of the students in the program do laboratory research, most of them pursuing full-year projects in the traditional science departments.

Dr. Kiorpes stressed that making the neural science program work requires interaction and cooperation among departments, faculty members, and deans. In particular, deans have to be willing to give faculty members release time from their own departments so they can participate in neuroscience courses.

The university's newest elective in the program, Computational Neuroscience, is a good example of interdisciplinary co-

Drs. T. J. Mueller, Harvey Mudd College, Lynn Kiorpes, New York University, and Don Dennis, University of Delaware, discuss how educational technology is stimulating science teaching in interdisciplinary fields such as neuroscience.

operation, said Dr. Kiorpes. Students work with computers to familiarize themselves with cutting-edge research tools such as imaging and modeling software. The course is taught by a cognitive psychologist in cooperation with faculty members from the physics department and the neuroscience program. According to Dr. Kiorpes, interdisciplinary curriculum development and flexible technology encourage cooperation among faculty members from different disciplines.

Harvey Mudd College

Dr. Mueller offered general thoughts on how to encourage interdisciplinary teaching. He noted that the current system of academic promotion and tenure puts too high a premium on disciplinary boundaries and should focus instead on student learning. He offered some guidelines for student-directed learning: Let students formulate questions, discover solutions, and teach their peers. The faculty, on the other hand, should guide, facilitate, and motivate.

Dr. Mueller described Neurobiology, an experimental course he offered last year. He told the 30 students in the class to select a specific, personally interesting question in neurobiology. Students came back with questions such as How does vision work? Why does my grandmother have Alzheimer's disease? and

What happens to my brain when I learn to play tennis better?

After leading a discussion on what constitutes a good question and how to go about answering it, Dr. Mueller asked students with similar questions to organize into groups of two or three. The groups were responsible for giving the class periodic progress reports on their findings.

Dr. Mueller provided each group with software for producing an interactive multimedia program. Students were required to produce a computer-based tutorial based on the group's topic along with supporting material. Students were graded by their peers, who evaluated the group presentations and the computer-based tutorials. There were no exams, and Dr. Mueller gave only four lectures—all at the students' request.

Dr. Mueller reported that the students were enthusiastic about the class, although some said a little more guidance from the instructor would have been helpful. He concluded that when a course relies on student-directed learning, "through their naiveté, students will ensure the topic is interdisciplinary." Instructors need courage and dedication to work outside their discipline. "It will be disorganized. It will be fun. It will be a real learning experience," he concluded.

University of Delaware

Dr. Dennis described several changes that the University of Delaware has made to its biochemical science curriculum to introduce students to technological advances and encourage interdisciplinary teaching and learning.

He explained that the university has a five- to six-week period between the fall and spring semesters, Winterum, during which students are encouraged to pursue special projects. An intensive laboratory course in molecular biochemistry is offered during this period. The class, which runs eight hours a day, is taught by physical chemists, biochemists, and molecular biologists, crossing the traditional boundaries of these disciplines. It is offered to juniors, seniors, and graduate students and is the first stage of a research tutorial.

In the laboratory, students work at Silicon Graphics workstations. Using computer simulations, they are required to create site-directed mutations of a protein molecule. (Last year it was alkaline phosphatase.) Students use software tools to work through the steps of the process: visualizing the three-dimensional structure, selecting possible mutation sites, introducing these mutations into the protein, and measuring the enzymatic activity of the mutant proteins.

Dr. Dennis reported that although the course is time consuming and expensive, the laboratory is an effective teaching tool. "The students loved it," he said. One of the virtues of the course is that students are not limited to observing and are able to manipulate materials and see the results.

The second major change was the introduction of a course in computational chemistry, which helps students to better appreciate the relation between structure and function in chemistry. The course emphasizes how the laws of thermodynamics affect the physical properties of macromolecules and the mathematical calculations behind the study of the dynamics of macromolecules. The third change was to give undergraduate researchers access to advanced software that allows them to make new experimental approaches a part of their research efforts.

Discussion

Models of Interdisciplinary Teaching. One participant reported that her college offers a science ethics course that is team-taught by faculty from biology, religious studies, and philosophy and also includes physicians as guest speakers. Dr. Jay Labov, Colby College, said that Colby's division of interdisciplinary studies has developed several environmental studies courses that include biochemists, chemists, and economists in the teaching team.

Dr. Alice Burton, Saint Olaf College, said that at her institution much interdisciplinary teaching takes place in a tutorial-based peer college where students can create their own course of study. She described a student-initiated project on aging that integrates biology, economics, and spiritual issues involved in growing older.

The University of Tennessee, Knoxville's two-year undergraduate program in biology requires students to take an interdisciplinary course that includes two-week modules taught by faculty from the departments of library science, science journalism, and drama (to teach public speaking), said Dr. Neil Greenberg. The intent is to sharpen students' communication skills. Dr. Greenberg added that the English department is developing a program in grant writing for science majors.

Bryn Mawr College is preparing a series of courses for an interdisciplinary program in environmental studies, said Dr. Paul Grobstein. Some of these courses will be taught by faculty from both the sciences and the humanities. This kind of interdisciplinary approach benefits both students and faculty, Dr. Grobstein said.

Dr. Jameel Ahmad said that Cooper Union offers courses in finance and business law to its engineering majors because it believes that engineers must understand the global marketplace.

Resistance to Interdisciplinary Teaching. Most participants expressed strong support for interdisciplinary approaches, although some reported that the concept has met resistance on their campuses. Reasons for this resistance include concerns about cost and about whether straying outside the boundaries of traditional disciplines would adversely affect students' employment prospects. One participant said that student-designed programs may not be credible to employers, while others argued that many employers are seeking individuals with problem-solving ability.

The panel agreed that faculty members may need to seek grants and obtain support from deans and heads of departments to develop interdisciplinary courses, but they argued that the results of such efforts are worthwhile. Noting that most graduates of New York University's neuroscience program go on to medical school, Dr. Kiorpes said that she felt much more comfortable knowing that these students had a deep understanding of the scientific method.

Group 3: Creating and Adopting New Learning Technologies: Strategies for Involving Science Faculty

Bates College □ Martha Crunkleton, Ph.D., Moderator
University of Miami □ Michael S. Gaines, Ph.D.
University of Wisconsin–Madison □ Lillian Tong, Ph.D.
Cogito Learning Media, Inc. □ Linda Chaput, Resource

Bates College

Issues confronted during the introduction of educational technology at Bates College have included making the technology accessible to all students, evaluating costs, distributing site licenses, and providing faculty with the time and resources to learn about the technology, said Dr. Crunkleton.

Undergraduate involvement with technology has accelerated because entering students are more computer literate than previously and a larger number now arrive on campus with a computer. Several "smart" classrooms have been created on campus, the library has developed on-line services, and the college has carried through with its commitment to the network.

Computer-based three-dimensional visual material and simulations have been found to be particularly effective for teaching. Subjects such as plate tectonics in geology are more effectively presented on computers than on a college blackboard. In neurobiology, the effects of different neuropathways on neuronal excitability can be demonstrated.

Computers permit undergraduates to communicate 24 hours a day, if desired. Faculty find that these interactions promote greater intimacy in the classroom. Some students participate more in class after having an opportunity to express themselves in the relatively unthreatening environment of a computer network. Computers also enable students to design experiments from the outset. This increased involvement may encourage more students to stay in science.

Science curricula that have been developed for use online include Mathematical Models in Biology Population Growth, and Predator-Prey Ecology. Computers have made complex concepts, such as fast Fourier analysis, accessible to undergraduates. Computers also affect the use of laboratory instrumentation, enhancing such areas as electron microscopy, flow cytometry, polymerase chain reaction, atomic emission spectrometry, and hydrology. Dr. Crunkleton said that laboratories using computers have become some of the most popular on campus. The development of home pages has produced a similar result, with network usage increasing measurably.

Dr. Crunkleton concluded by observing that what is most difficult in developing educational

Dr. Lillian Tong of the University of Wisconsin–Madison listens as Dr. Martha Crunkleton of Bates College moderates a discussion on ways that colleges and universities can successfully integrate technology into the science curriculum by involving faculty members in all phases of planning.

technology is anticipating the effects it will have on the college's constituencies—primarily undergraduates and faculty members. Computers have a pronounced effect not just on the exchange of information but on patterns of human interaction in laboratories, lecture halls, dormitories, and other campus sites.

University of Miami

Systems need to be developed that aid the student-faculty mission of teaching and learning, but high technology is not a substitute for innovative approaches in the laboratory and classroom. For example, material that can be found in books often is passed off as a high-technology tool for education when, in fact, it is just a collection of images, said Dr. Gaines.

The University of Miami has taken a different approach, using pedagogy to drive technology. The World Wide Web is being used to organize and present course material to undergraduates. The Web offers the advantage over specialized systems of being independent of computer type, and Web server and browser (reader) programs are available for all major operating systems. In addition, the Web makes it easy to construct complex pages that combine text and graphics—every faculty member or student can easily produce Web home pages.

The university is beginning to use the Internet Relay Chat system to enable interactive discussion among students and faculty. This system is often viewed as entertainment, but the intent of its developers was to produce a text-based conferencing system for use in education. In the upper-level mathematical biology course, students were more willing to talk to each other and to faculty via Internet Relay Chat than in person, at least initially, said Dr. Gaines. Students who participated claimed to have a more positive view of the university after the experience.

First-year biology laboratories are being redesigned from the ground up to integrate technology into the courses. Laboratories will have microscopes equipped with video cameras and computer video capture. Students will capture images, integrate them into laboratory reports, and make presentations using video projection facilities. Course materials, including student presentations, will be available on the Web. In general physiology, instructional materials are already on the Web, and students transfer the results of their experiments directly onto Web pages.

The ultimate goal is to provide efficient access to course materials in an exciting learning environment, said Dr. Gaines. He concluded by commenting that faculty must be participants, not observers, in the development of educational technology.

University of Wisconsin–Madison

The Center for Biology Education at the University of Wisconsin–Madison operates in a unique environment that comprises 68 academic departments for the biological sciences but no biology department and no major in biology. The departments are research based and the administrative structure is highly decentralized, making it difficult to adopt or create new learning technologies. The center has played a key role in strategies to overcome these hurdles by providing a unified effort on behalf of the biological sciences communities.

A major constraint regarding use of technology in the classroom is that many lecture halls lack digital and video projection capabilities, computers, and videodisk players. Rather than waiting for a costly total lecture hall renovation, the center has developed a lending program to provide the equipment necessary to use technology in lecture halls. Few faculty members will expend the time and effort to consider how technology can be used to improve learning in their courses unless the equipment is already available.

Another hurdle is the lack of communication among faculty about using technology for learning in biology. The Center for Biology Education has developed forums for discussion about the use of technology that identify what is being implemented, evaluate biology instructional materials, and promote campuswide sharing of resources and ideas on the application of technology. Discussions have included topics such as uses of e-mail and the World Wide Web in instruction, software in laboratories, simulation software in lectures and laboratories, animations, and biology videodisks.

As at many large universities, diverse demands compete for limited faculty time at the University of Wisconsin-Madison. Faculty members appreciate help in locating materials available for use in courses and learning to use equipment. Demonstrating what is available and facilitating networking, both internally and externally with other universities, often stimulate development of materials that better fit faculty needs.

The Center for Biology Education has developed several programs to promote improved teaching of biology. The center has facilitated cooperation and has helped put in place an infrastructure that will support continued growth in the use of technology in biology education while minimizing cost. Dr. Tong noted that students should conduct laboratory research as soon as possible and that the use of educational technology helps speed up this process.

Cogito Learning Media, Inc.

Ms. Chaput described efforts by Cogito Learning Media (formerly Interactive Sciences, Inc.) to address the major challenge of creating and adopting new learning technologies. Her strategy, based in part on her extensive experience with educational publishers, is to first assess the external environment for educational technologies.

By 1998, 93 percent of new technologies deployed on campus will be for instruction and research. Management will use only about 5 percent of the new systems. Accompanying the increased use of educational technologies will be various institutional changes. Accessibility to public laboratories will increase, as will dormitory access to campus networks. Online communication is expected to proliferate along with growth in distance-learning capacity.

Universities are supporting new technologies by developing campuswide standards for hardware and software; integrating computer services with allied departments; expanding the availability of computer networks across campus, even in classrooms; investing in the development of digital libraries; and establishing networks of research databases.

Ms. Chaput described several approaches that university administrators and faculty members can use to enable learning with new technologies. These include integrating the development of new instructional and curricular media materials with traditional teaching in classrooms, libraries, and teaching laboratories; providing support, recognition, and rewards for faculty who develop meritorious technology-based materials for

Ms. Linda Chaput of Cogito Learning Media, Inc. and Dr. Michael Gaines of the University of Miami respond to questions about the challenges of disseminating new educational technologies to the science and education communities.

research and teaching; assessing performance of technology-based materials against curriculum and student histories; and building collaborative networks of students and researchers worldwide.

Growth in the use of mixed-media technology is unlikely to affect the production and sales of books. Publishing, Ms. Chaput noted, has never been healthier. Expansion of educational technologies requires criteria for assessment. If scientists and educators fail to develop guidelines, the public is likely to take over responsibility for doing so.

Discussion

Participants discussed valid methods for the assessment of multimedia technology, faculty ambivalence about earning royalties from software development, and differences between faculty members' teaching methods and students' learning styles. One novel assessment approach involves peer review of multimedia technology, which earns merit units for the faculty member that are then converted to increases in monthly base pay. Participants noted that although most faculty members at an institution may have access to computers, not all use them.

Student Access to Technology. Participants felt the need for market evaluations of computer literacy and ownership among incoming freshmen. Without reliable indicators of technological preparation, it is difficult for institutions to formulate effective strategies for providing student access to technology.

It is a misperception that some institutions are already providing entering undergraduates with computers. Dr. Susan Henry, Carnegie Mellon University, stated that, despite reports to the contrary, the university did not provide computers to new undergraduates. The cost of offering computers could adversely affect the financial aid that many institutions provide to students on the basis of need. Furthermore, disciplines differ in their technological needs. Providing undergraduates with computers when they enter is risky because half of the students will change their major in subsequent years.

One option to consider might be a program to lease computers to undergraduates, suggested Dr. Peter Bruns, Cornell University. Another might be to create campus computer centers in dormitories, libraries, and elsewhere. Exposing undergraduates to educational technology in both lectures and laboratories would likely stimulate students' interest in obtaining their own equipment if they did not already have it. Dr. Tong, however, expressed concern that as technology continues to advance rapidly, equipping more than one technology center at a time may squander limited institutional resources.

Some participants felt that a campus that is already networked would drive computer usage by undergraduates, whereas others argued that the opposite might be true. Attendees also noted that gender differences may affect students' level of comfort with educational technology.

Software Platforms and Equipment Compatibility. The most appropriate platform for software development remains a contentious issue. Dr. William Tramontano, Manhattan College, noted that whereas 92 percent of the computers at his institution are IBM-compatible, he expected Apple equipment to be widespread at other locales because of the company's strategy of making its products easily accessible to schools. Resistance to Apple equipment may occur, however, because of the difficulty of interfacing it with other systems.

Participants also focused on the practicality and compatibility of various technologies. The World Wide Web, they noted, can serve both IBM and Macintosh platforms. For both systems, however, modem speed is important and special lines are needed for high-speed video transmission. Often unresolved are issues such as how to integrate telecommunication lines with libraries and how to make them accessible to undergraduates, faculty, and administrators.

Braving the New World: Resources and Realities

Educational technology simultaneously holds great promise for and presents enormous challenges to undergraduate education. The promise is that technology can make science more attractive and interesting to students, motivate more students to pursue science careers, and improve science literacy among those who choose other careers. The challenges include not only constraints on both human and financial resources but also human resistance to changing established work styles.

In Session III, program directors focused on the realities faced by faculty members and institutions trying to achieve the promise of educational technology. Issues highlighted included how to integrate educational technology into undergraduate science education, determine how best to assess and disseminate new technologies, develop software programs for biological modeling, and decide whether to use off-the-shelf software or develop it from scratch.

Participants identified several factors that must be present to ensure the success of educational technology. These include accessibility and flexibility, institutional commitment, a decentralized infrastructure, continuous maintenance of equipment, and user training. Long-term planning that identifies future needs early and takes into account the rapid obsolescence of technology is also crucial.

Assessment of educational technology is critical to providing a direction for its future development. Although many faculty members report good subjective responses from students who have used educational technologies, objective measures of student performance (such as multiple-choice tests) have so far provided less encouraging results. However, the adequacy and appropriateness of such standard assessment tools for the evaluation of technology-based courses and programs is a matter of some debate. One program director suggested that assessment efforts must take a range of variables into account, including the style and experience of instructors and the level and goals of students.

Educational technology can be particularly useful in teaching biological structure because it enables three-dimensional visualization of structures such as atomic orbitals that students often have difficulty conceptualizing because they cannot be seen. Interactive technologies engage students actively in simulated experiments.

Whether to develop custom software, buy an off-the-shelf package, or modify existing software depends on a variety of factors, including the resources available and how well existing software meets the user's needs.

Braving the New World: Resources and Realities

University of Illinois at Urbana-Champaign □ Sondra Lazarowitz, Ph.D., Moderator
Rice University □ Frederick Rudolph, Ph.D.
Wofford College □ B. G. Stephens, Ph.D.

University of Illinois at Urbana-Champaign

The technological tools available to educators are being developed at a breathtaking pace. This powerful technology allows for exciting innovations in science education, but it can also be overwhelming. Student and faculty response can range from enthusiasm to intimidation. Dr. Lazarowitz suggested several institutional strategies to integrate the range of responses to technology with educational objectives.

These strategies include creating communities of undergraduates or faculty that support their members as they adapt to technological innovation; making technology accessible and interactive and providing opportunities for self-fulfillment when using it; adopting technology initially in the development or revision of introductory courses; encouraging individuals with an inclination toward technology to assume leadership roles; and creating collaborations between communities, for example, between faculty from various disciplines, between faculty and undergraduates, and between faculty and K–12 teachers.

At the University of Illinois at Urbana-Champaign, computer simulations are used in courses such as Biology 120–122, a combined lecture–wet laboratory sequence where a computer laboratory supplements the lectures and hands-on laboratories. Interactive software written or adapted by faculty allows students to experiment at the computer. Collaborative software such as PacerForum that supports the creation of virtual learning communities fosters interactions among students and increases student-faculty contact. Posting of curriculum materials on the World Wide Web has actively engaged students in using the technology.

Dr. Lazarowitz identified several factors that are related to success in the introduction of educational technology. Continuous, accessible, and reliable support—in training, maintaining hardware, operating the computer laboratories, providing software upgrades, introducing innovations, and solving problems—is essential. The technology must be readily accessible and easy to use. It is critical that a university's administration recognize the value of educational technology and provide continuing leadership and support through the creation of campus computer laboratories and educational technology centers.

Faculty should be encouraged to "buy into" technologies by being given an opportunity to peer-review them, Dr. Lazarowitz

Drs. Sondra Lazarowitz of the University of Illinois at Urbana-Champaign and Frederick Rudolph of Rice University discuss strategies, such as flexible planning and ongoing training, that ensure the support of the faculty for educational technology.

said. She added that, in her experience, faculty members are more enthusiastic about the introduction of technology when they understand what it is intended to accomplish. Teaching assistants and undergraduates should also be given the opportunity to evaluate new technology.

Technologies must be applied flexibly. What works in theory may present problems in practice. The university has employed an adaptive strategy, monitoring the use of technology in courses and being responsive to the needs of students and faculty.

The institution's recognition of the need for a flexible approach has led it to focus on an important challenge for the future: how to adapt educational technologies to diverse situations and student populations. Issues being considered include whether BioCalc can be adapted for use on other campuses with different resources, needs, and student populations (for example, prefreshmen who would otherwise be enrolled in remedial math) and whether educational technologies developed for introductory biology and calculus work in distance learning programs for high school and middle school students.

Rice University

Development of electronic technology for educational use poses both problems and great potential for higher education. The promise that such technology holds is limited on many campuses by funding; access to equipment and software; training; and, very often, reluctance on the part of the faculty to embark on new teaching approaches.

As part of a recent reaccreditation process, Rice University conducted a self-study on the role of electronic technology in education. The self-study committee evaluated current and future needs for and uses of computers, information technologies, audiovisual capability, multimedia technology, and interactive teleconferencing in the teaching mission of the university.

The conclusion was that new technologies should enhance the university's traditional emphasis on personalized education with greater use of multiple resources and alternatives to the traditional lecture format and laboratory exercises. A major concern of the committee was that the institution's facilities would not allow significant expansion of these initiatives. Failure to equip classrooms for electronic use can be a major limitation.

An additional concern is that the development of new teaching materials can take a lot of time that may not count significantly for promotion or as a scholarly pursuit. Training faculty in the development of such materials requires a significant commitment on the part of both the university and the individual.

Use of electronic technology will vary with discipline. The self-study concluded that each school in the university must oversee its own development and implementation, with appropriate budgetary input from the administration. Planning must be continual, consultative, and focused and must lead to practical results. Some schools or departments will develop their own materials for educational use; others will use materials developed at other institutions.

Examples of software developed at Rice include the Galileo Project, a history-of-science program; X-ray View, an undertaking to explain x-ray crystallography; and a course on wasp behavior. Software development requires a significant commitment of time and funds. Using materials developed elsewhere requires fewer resources, but the materials may not meet all of the projected needs.

The university has created initiatives to upgrade classrooms with technology, develop a campus computer network, hire support staff, obtain computers and other equipment, and offer training sessions. A cable television company was permitted to install access to cable channels in the university dormitories if it simultaneously wired the rooms for Internet access at no charge.

Computers and related equipment purchases currently comprise about two percent of the university's annual budget (approximately $5 million). By comparison, private-sector corporations involved in information technology spend 5–6 percent of their annual budgets on similar purchases. Unresolved is whether Rice University should try to match this level of expenditure.

In summary, Rice has made a significant commitment to the

Dr. B. G. Stephens of Wofford College explains the College's development of a multimedia classroom and new materials for science teaching.

educational use of technology and has decentralized technical and educational support to allow local control over development. These initiatives may serve as a model for other institutions.

Wofford College

At Wofford College, the objectives of bringing educational technology to the campus included empowering faculty with the knowledge of how to use it and providing them with greater academic flexibility.

The college received a grant from the Olin Foundation to construct a building where classrooms are equipped with sophisticated communications and projection equipment. With a subsequent grant from HHMI, the college retrofitted a standard classroom with some of the technical capabilities found in the new building. This facility is located across the hall from a wet laboratory where students perform discovery-based experiments.

The electronic classroom, which is extensively used by biology faculty and students, has also been used in Wofford's science outreach program for 7th- and 8th-graders. Each student taking part in the outreach program receives a computer, modem, CD-ROM player, multimedia software, and an e-mail account at the college. Students participate in the program for two weeks during the summer and subsequently become part of an electronic network that includes Wofford science faculty. Forty-five students and six faculty members are currently involved in this network.

Workshops have been conducted to facilitate faculty use of multimedia for lecture presentations. About 20 percent of the faculty have become producers of multimedia materials and, in the process, intelligent users of these and other technology resources. Faculty members who were initially reluctant to use technology were won over by the opportunity to learn new educational techniques.

South Carolina is in the forefront of telecommunications development and operates a satellite-based digital television system that can potentially broadcast 32 channels. A small downlink receiver and modulator are all that are required to receive signals. This system is a crucial resource for the college's outreach program, said Dr. Stephens.

Teaching rather than research productivity is emphasized in the promotion and tenure process at Wofford College. Faculty, said Dr. Stephens, will not be replaced by educational technology itself but by people who can use the technology.

Discussion

Importance of Planning and Assessment. Off-campus sites that want two-way communication need additional equipment to uplink with a satellite. Such examples underscore the importance of planning for future equipment needs. Planning for obsolescence is also important. Dr. Lazarowitz said that the University of Illinois at Urbana-Champaign has dealt with obsolescence by using advanced equipment in more advanced courses and transferring it for use in lower-division courses as newer equipment becomes available.

Continuous assessment of both hardware and software is essential, said Dr. Stephen Arch, Reed College. A well-thought-out assessment policy accommodates evaluations during both development and use, interviews with undergraduate and faculty users, input when possible from a college of education, and ability to make changes on the basis of the feedback received. Dr. Alice Burton, Saint Olaf College, reported finding that consumer-grade equipment has greater stability than industrial-grade equipment.

Encouraging the Use of New Technology. Dr. Johnnye Jones, Hampton University, described strategies to enhance faculty involvement with technology, including ongoing workshops for faculty, graduate students, and undergraduates. Another scenario is to make use of the expertise of computer science faculty members to provide guidance to faculty from other disciplines. Precollege teachers can be invited to workshops on campus to engage in curriculum development and learn how to incorporate technology into their classrooms.

Emphasis on the use of educational technology can be incorporated into new faculty orientation sessions, suggested Dr. Martha Crunkleton, Bates College. A raffle for computer equipment can draw faculty to computer fairs, where they can familiarize themselves with state-of-the-art technology. However, Dr. Paul Grobstein, Bryn Mawr College, said that until faculty are convinced that technology will improve research and education, overemphasizing its importance is misguided.

Dr. Rudolph said that administrative decentralization is desirable because disciplines differ significantly in their technological requirements and departments need flexibility when making decisions on equipment purchases, software and curricula development, and related issues. Faculty members need release time to develop technology-oriented curricula. Faculty who "buy into" technology early often develop sustained appreciation for its educational value. Faculty who are not specifically introduced to technology often do not think about how it might be applied to lectures and laboratories.

Dr. Lazarowitz observed that it is inconsistent for an institution to train graduate students in the use of educational technology while failing to give junior faculty consideration for the use of such technologies when tenure decisions are made.

Faculty at some institutions have divided opinions about the use of computers, said Dr. John Paznokas, Washington State University. Some prefer to give seminars without depending on technological devices. Others consider that candidates' expertise in their discipline should be the critical factor in tenure decisions, independent of technological competence.

Institutions often find it difficult to coordinate the training of faculty, whose competence with technology spans a broad spectrum. Coordinating faculty members' audiovisual needs and ensuring that lecture halls and laboratories are appropriately equipped can be challenging. Carts can facilitate the transfer of projectors and other equipment from one location to another.

Group 1: Assessing and Disseminating Educational Technology

University of Iowa □ George D. Cain, Ph.D., Moderator
City University of New York Hunter College □ Shirley Raps, Ph.D.
Michigan State University □ Steven R. Heidemann, Ph.D.
National Research Council □ Nancy L. Devino, Ph.D., Resource

University of Iowa

Fundamental to any discussion of assessment, Dr. Cain said, is what to assess and how to assess it. He noted that assessments of students' attitudes will differ from those of performance, effectiveness, or efficiency.

Dr. Cain described efforts at the University of Iowa to assess student response to the use of educational technology in biology courses. Four locally developed computer simulations are used as aids in the teaching laboratory of the introductory course for biology majors. The programs simulate the nerve impulse, population growth, population genetics, and predator-prey interactions. Unlike most comparable software, which students use interactively with minimal supervision, these simulations were designed to be used by all students (working in groups of two or three) in a structured laboratory with teaching-assistant supervision.

At the end of each semester, students are asked whether they feel that the computers and simulations helped them to understand the relevant biological principles. Typically, about 70 percent of students say that they found the simulations helpful; about 25 percent say that they would have liked more time to interact with the programs.

For this reason, the programs were translated to Macintosh format and incorporated into a new computer-assisted laboratory for undergraduate biology, which was remodeled and equipped with HHMI support. A portion of the laboratory is set up as a station where faculty can create computer-assisted presentations and classroom or laboratory exercises.

One professor used computer-assisted presentations in Biology of the Brain, a course for nonscience majors. He used electronic presentations in the first half of the course and changed to a traditional lecture and discussion format in the second half. Although students responded well to the electronic presentations in class, they said in their course evaluations that the professor had covered that material too quickly. Overall, the students strongly preferred a course that combined electronic presentations with traditional lectures and discussions.

In the introductory biology course for science majors, which is team-taught to over 400 students, one of the lecturers used computer-assisted presentations and the other two used a tradi-

Dr. George Cain (right) of the University of Iowa demonstrates to Dr. Peter Tobiessen of Union College one of several software simulations developed at the University for teaching such areas as neuroscience and population genetics in introductory courses.

tional format. Students who took the course during the first semester (most of whom were biology majors) strongly preferred the computer-assisted lectures, whereas the second-semester students (most of whom were prepharmacy majors) disliked them. Another professor used electronic presentations in an advanced animal physiology course. Although students taking the course generally disliked them, faculty members who evaluated the instructor's teaching found that the presentations improved his organization of the course.

Assessments of educational technology should take into account a range of variables, including physical facilities, the style and experience of the instructor, and the level and goals of the students, Dr. Cain concluded.

Michigan State University

The university has invested part of its HHMI grant in an effort to use technology to enhance lecture performance in large introductory biology courses. A team of faculty and staff developed a multimedia instructional computer program, the BioScience Explorer.

The program's central feature is 13 full-color animations of standard introductory topics (including oxidative phosphorylation, transcription, translation, and replication) that are intended to help students think in terms of three-dimensional molecular structures and processes. In addition to an illustrated glossary of clickable "hot words," the program includes past multiple-choice examinations in an interactive format in which each possible answer is associated with an explanation of why that choice is correct or incorrect. Students can access the program in computer laboratories located throughout the university campus, including two that are directly adjacent to the wet laboratories used for the introductory course.

Subjective response to the program has been favorable according to student questionnaires, improvement in course ratings by university-wide instructional rating forms, and increased use of the program (for example, in upper-level genetics courses and in first-year biochemistry for medical students). Nearly all the students used the software, said Dr. Heidemann, most for about an hour at a time. In evaluations, students said that the software helped them and that they would recommend it to the next year's class.

To test the software's effectiveness objectively, Dr. Heidemann compared the performance of students using BioScience Explorer with that of previous classes of students on 17 multiple-choice questions from previous exams. (Substitutes for these questions were incorporated into the practice exams in the program.) The questions directly addressed material he had covered with the use of BioScience Explorer in 5 lecture hours during the first 19 lecture hours of the course. The lecturer, "course-pack" notes, and exam format were the same for both groups of students.

No improvement in exam performance was noted from the use of BioScience Explorer. Dr. Heidemann concluded that more objective evaluations are needed to find out which educational technology initiatives work and which do not. The results of his study made him question whether tools such as BioScience Explorer help students to learn biological concepts.

City University of New York Hunter College

Dr. Raps described two components of Hunter College's program to disseminate and assess educational technology. The first component is a techniques facility for undergraduates, which is intended to provide an unintimidating environment where inexperienced students can learn to use scientific instruments and thereby understand common laboratory techniques. The facility contains equipment found in a working research laboratory. Each student works under the supervision of a more experienced peer tutor, using a workbook of self-paced modules.

The Department of Biological Sciences has made successful completion of the workbook modules a prerequisite for undergraduates who want to do laboratory research, Dr. Raps said. Workbook completion has also become a prerequisite for participation in the college's HHMI-sponsored summer work-

Drs. George Cain, University of Iowa, Shirley Raps, City University of New York Hunter College, Steven Heidemann, Michigan State University, and Nancy Devino, National Research Council, discuss strategies for assessing and disseminating educational technology.

shops for undergraduates and high school teachers. Several of the college's other research programs also require undergraduates to complete a techniques facility training session.

Responses to questionnaires administered to both students and research mentors before and after students complete the workbook modules indicate that the facility is becoming an essential component of students' successful participation in research, Dr. Raps said. Students also value the facility as a center for discussion and supportive interaction. A poster about the techniques facility was presented at the 1995 annual meeting of the American Society of Cell Biologists. Several publishers are considering publishing the workbook.

The second component of Hunter's technology program consists of outreach to high school teachers. The program familiarizes teachers with recent scientific advances by giving them the opportunity to use modern techniques in a research setting and helping them develop strategies to take the excitement of modern science back to their high school classrooms.

Teachers from New York City high schools are selected to participate in an intensive, techniques-oriented summer workshop in either biotechnology or neurobiology. The workshops are team-taught by Hunter College faculty members, assisted by experienced high school science teachers. Before participating in the summer workshops, the teachers complete the techniques facility laboratory exercises and spend a day in the undergraduate learning center, working with commercially available interactive computer software that introduces them to current developments in either biotechnology or neurobiology.

Upon completing the workshop, teachers each receive up to $1,000 worth of supplies, kits, and equipment to use in their classrooms. Commercial kits are purchased for teachers who attend the biotechnology workshop. The college has developed its own kit and accompanying laboratory manual for the neurobiology workshop because no such materials were commercially available. The neurobiology kit and manual are likely to be distributed commercially in the future.

Before and after the workshops, the teachers complete questionnaires designed to assess the workshops' impact on students' interest in science.

To expand the reach of the summer workshops, teachers and selected students who have used the kits are invited to visit the campus and tour the college's science facilities. During these visits, Hunter undergraduates give talks and demonstrate the use of modern scientific equipment. Essays submitted by the students and feedback from their teachers indicated that the first year of the program succeeded in encouraging student curiosity about scientific research and interest in learning further about science in college.

National Research Council

The National Research Council's Committee on Undergraduate Science Education (CUSE) has received HHMI funding for two projects that complement the Institute's efforts to provide undergraduate program directors with greater access to electronic information and assistance in incorporating information technology into undergraduate science courses.

First, CUSE has developed an extensive database that contains information about model science courses, national organizations and programs involved in undergraduate education, and summaries of research dealing with science education and pedagogy. The database is available on the Internet. URL: <http://www2.nas.edu/cusehome/index.html>.

Dr. Devino provided illustrations of the kinds of information found in the database. She noted that members of the science education community can submit information to NRC via the Internet for possible inclusion in the database. CUSE is developing criteria for deciding what other information to include and examining how to link the database electronically to other organizations, she said.

Second, in collaboration with

other NRC education initiatives, CUSE is working with a panel of faculty, students, higher education institutions, and software developers and publishers to establish guidelines and benchmarks for improving access to and quality and use of software for undergraduate science instruction. This two-year project will examine such issues as the kinds of information technology products available, their quality, the extent to which they are used, evidence that they enhance student learning, and impediments to their use. The panel's report will be available in late 1997 or early 1998.

Discussion

Assessing Educational Technology: Moving the Goalposts? Dr. Jay Labov, Colby College, suggested that essay questions might have been more appropriate than multiple-choice questions to assess the BioScience Explorer course. Dr. Heidemann said that an educator at Florida State University was doing a controlled experiment to study the impact of educational technology on student performance on essay questions. He added that educators need to decide what they want their students to know, rather than changing their goals according to their methods. He said that he is not in favor of "moving the goalposts" as education experts seem to do.

Dr. Paul Grobstein, Bryn Mawr College, said that he was not entirely surprised by the outcome of Dr. Heidemann's study. New technology provides a way to attract students to science who might not have been there before, he said, as well as a sophistication of understanding that educators have not previously been able to reach. Dr. Grobstein added that educators would like to know if using technology can change the way people understand science. However, this requires different forms of assessment than those used in the past.

Dr. John Paznokas, Washington State University, suggested that assessment should distinguish between high school and college students, who are at quite different cognitive levels, to evaluate how well educational technology can help each group to develop its level of understanding.

Goals of Educational Technology. Dr. James Freed, Ohio Wesleyan University, said that learning should not stop at the end of a class. Rather, teaching should be concerned with how to access information. He asked if Dr. Heidemann had assessed how well educational technology was doing with respect to that goal. Dr. Heidemann said that he had not done such an assessment, but agreed that it was important to encourage students to think on their own.

Dr. Michael Gaines, University

of Miami, said that the two most important goals of educational technology are achieving conceptual understanding and stimulating excitement about science in nonscience majors; these goals suggest different types of assessment. Dr. Grobstein said that the new technology is exciting because it enables educators to redirect their teaching goals. Rather than simply being able to pass the Graduate Record Examination or the Medical College Admission Test, he said, students should be able to think, create, and be curious on their own. New technology makes these goals easier to attain.

Group 2: Modeling and Teaching Biological Structure

California Institute of Technology ☐ Nathan S. Lewis, Ph.D., Moderator
State University of New York at Stony Brook ☐ R. David Bynum, Ph.D.
New York University ☐ Tamar Schlick, Ph.D., Resource
Carleton College ☐ David G. Alberg, Ph.D.

California Institute of Technology

The goal of the Caltech Chemistry Animation Project is to combine the techniques of the broadcast animation industry with advances in computational methods to revolutionize the way students view their chemical world.

The project uses state-of-the-art graphics and visualization methods to prepare instructional aids for teachers on various topics in the biology and chemistry curriculum. The goal of the work is not to produce programs that assist in problem solving or in algebraic manipulations but to focus on visual presentations and real-time visual manipulations of a variety of concepts.

Completed projects depict the three-dimensional shapes of atomic orbitals, stereochemistry, crystal structures, shapes of molecules, nucleophilic substitution, and advanced concepts in organic chemistry (for example, the Diels-Alder reaction). Additional projects include other basic organic reactions, trends in atomic size and ionization energies in the periodic table, and hybridization and resonance. These topics are released on videotape.

The video animation is overseen by highly skilled professionals from the television and film industries. The resulting broadcast-quality video footage is digitally mastered in Hollywood. Professionally composed music and professional narration are added; sound editing is performed by award-winning audio professionals. Support from HHMI and other organizations helps defray production and distribution costs.

The first six tapes, which focus on basic concepts in the chemistry curriculum, have been released in the United States. Arrangements are in progress for distribution in Japan, Australia, Germany, England, New Zealand, South Africa, and other countries. After they obtain the first videotape from Caltech, instructors can make unlimited copies for their students. Further information about the videotapes can be obtained from Caltech's World Wide Web site <http://bond.caltech.edu>.

State University of New York at Stony Brook

In his institution's experience, said Dr. Bynum, the instructional methods frequently used in teaching do not give sufficient

Drs. Nathan Lewis, California Institute of Technology, R. David Bynum of the State University of New York at Stony Brook, Tamar Schlick of New York University, and David Alberg of Carleton College field questions from program directors on their approaches to teaching modeling of biological and chemical structures.

attention to the student's personal knowledge or naturally inquisitive nature. Traditional tools such as textbooks and visual aids present a one-way flow of information, with little feedback or cooperative interaction.

Combining the faculty and resources of the Division of Engineering and the Division of Biological Sciences, the university built a computer laboratory that was designed to overcome these limitations. The laboratory is used by high school students, undergraduates, and high school teachers to advance their understanding of computer systems and computer modeling in biology.

The computer modeling course taught in the new laboratory is based on two key philosophies. First, learning is the result of the construction of knowledge and the role of the instructor is to assist students in increasing their knowledge base. This approach has been termed the constructivist approach to learning. Second, students and instructors use learning tools as opposed to teaching tools.

Rapid advances in computing and telecommunications have presented new opportunities for creating student-centered learning environments. Multiple views of concepts (graphic, numeric, and symbolic representations), active engagement, and effective feedback systems leverage the power of the student-based learning laboratory. Cooperative learning, collaborative skills, group processing, and positive interdependence techniques are all used. New knowledge results from students' efforts to situate present information or experiences within their network of existing knowledge. The course was designed using this conceptual framework.

The purposes of the course are to deepen students' understanding of biological concepts studied in other courses; provide new tools (conceptual frameworks, quantitative methods, models, and software) that can be used in other courses as well as in students' professional careers; enrich students' understanding of modern methods in the biological sciences, especially modeling techniques that are at the frontier of research; and encourage students by the use of individual projects to continue using these tools in more advanced research applications.

The course opens with an introduction to modeling and to the Stella modeling software. A deterministic approach to modeling is taught by modeling rates of change in population, ecological systems, and physiological and biochemical phenomena. A key element of the course is the modeling of the nervous system.

Stochastic modeling is taught, using synaptic transmission as an example. Both the active and passive properties of the neuron are modeled. Dr. Paul Adams, an HHMI investigator, teaches the modeling of neural networks. After discussion and application of advanced modeling concepts, students design individual research projects, construct the model, and present their results. They are encouraged to continue these projects and develop new ones.

New York University

A combination of improved biological techniques, hardware, and software is changing the way research in biology and chemistry is done, said Dr. Schlick, HHMI associate investigator at New York University. The same developments are affecting the classroom; computers and high-quality visualization offer new tools for learning, experimenting, and developing ideas. Especially in the disciplines of structural biology and chemistry, where both qualitative and quantitative analyses are essential, computer tools can bring to life complex three-dimensional objects and help interpret molecular architecture and interactions in terms of basic physical laws (e.g., thermodynamics and quantum mechanics). Multimedia technology makes science more accessible and exciting to students and, by making the learners an active part of science, encourages the pursuit of scientific research careers.

The HHMI laboratory at NYU is interested in computational approaches to macromolecular structure. The group is developing new algorithmic approaches to molecular-dynamics simulations, in which molecular configurations are followed in both space and time. These animated snapshots of biomolecular systems provide insights into basic biological functions, which are intimately connected to structure. However, although high-speed computers make generation of these trajectory sequences a simple matter, it is a challenge to analyze systematically the voluminous data obtained.

With the support of HHMI's summer undergraduate training program, the laboratory has developed a user-friendly interface program to generate animated views from these dynamic simulations. A chemistry undergraduate adapted the visualization program MolScript for dynamic data. His new interface allows rapid viewing of the molecular trajectory and subsequent examination of individual frames in time to any degree of depth. Output can be produced in either black and white or color, on the screen and in hard copy. Such images can facilitate scientific analysis as well as enhance scientific publications.

Examples of static structures that have been modeled include bovine pancreatic trypsin inhibitor (BPTI) in water and the 13 residues of polyalanine. BPTI is a 58-amino acid residue protein that is important for digestion. A sample MolScript program was developed to depict protein structures.

The laboratory is also working on a multi-authored electronic textbook that will contain a survey of computer science tools, selected methods, and computer projects and case studies. The book is being developed as part of the Computational Science Education Project sponsored by the U.S. Department of Energy. A hard-copy version will also be produced.

General information about the work of the HHMI research group at NYU can be obtained from the group's World Wide Web home page <http://monod.biomath.nyu.edu>. Additional information about the electronic textbook can also be found on the Web <http://csep2.phy.ornl. gov/csep.html>.

Carleton College

Perhaps the best way to teach science at the undergraduate level, suggested Dr. Alberg, is to give students the opportunity to interact with current technologies that are driving science.

At Carleton College the departments of physics and astronomy, chemistry, and biology share the use of a Silicon Graphics Indigo2 Extreme workstation with molecular graphics/modeling capability. A major use of this computer, which was provided with HHMI support, is to create and display models of complex molecular structures such as proteins. Using the program InsightII, students can manipulate molecular models to

Drs. Ruth Reed of Juniata College, Lillian Tong of the University of Wisconsin–Madison, and Edward Funkhouser of Texas Tech University meet during the educational technology demonstration session.

gain insight into the relationship between molecular structure and function. The system can also be used to develop molecular graphics for presentations.

Connection to the Internet allows searching and downloading of data from archives such as the Brookhaven Protein Data Bank. Students use the system in an upper-division course to study various proteins and to illustrate presentations of their work with computer graphics. The workstation has also been used to write C programs for the study of chaotic systems used by physics students in a classical mechanics course. In addition, the system is used in faculty-student research collaborations to process and animate atomic-force microscope images of growing protein crystals and to simulate crystal growth by the Monte Carlo method.

Dr. Alberg noted that students usually do not need a lot of time to become familiar with a software program. In his experience, students who do require a lot of time usually will not be successful in using advanced educational technologies. He added that feedback from students who used the technology in a junior-year chemistry course revealed that advanced laboratory reports took too long to produce because students were focusing more on the presentation of data and less on the experiments.

Discussion

Discussion was brief and centered on technical issues. Dr. Schlick said that her group was working with algorithms developed for classical motion. To reduce the amount of data required for a given reaction, all atoms are moved but only some are specifically tracked by data coordinates.

In response to a question concerning the visualization of DNA, Dr. Schlick noted that the group's techniques involve curve splitting, the assignment of control points, and the assumption that the movement of base pairs can be represented as the motion of beads or cylinders.

Referring to Dr. Alberg's presentation, one participant suggested that the Carleton College program would be a very helpful prelude to a wet laboratory.

Group 3: Science Education Technology: Off the Shelf or Build It Yourself?

Case Western Reserve University □ Hillel Chiel, Ph.D., Moderator
Brandeis University □ Kent Reuber
University of Washington □ John Palka, Ph.D.

Case Western Reserve University

Dr. Chiel posed four questions that are helpful in deciding whether to use existing educational technology or create it yourself: What resources (time, money, and personnel) are available to create new technology? What resources can be devoted to documenting the technology and developing educational materials that enable other faculty members to exploit its potential? How well do existing technologies match your particular needs? Is it desirable to have technology that students can modify?

Dr. Chiel presented three case studies that illustrate the tradeoffs involved in this issue. Case Western Reserve's Introduction to Neurobiology course uses an off-the-shelf program, Axovacs, a simulation of the Hodgkin-Huxley model of the action potential. The program is written in BASIC, runs on IBM-compatible computers, and is available over the campus computer network, so students can run it on their personal computers at any time. It allows students to explore properties of the action potential as a whole, solve problem sets that accompany the program, and resolve questions that may occur during the computer laboratory session.

Dr. Hillel Chiel of Case Western Reserve University responds to questions in his panel session concerning whether to create new computer software or use off-the-shelf products for science education.

Axovacs has several advantages: It is fast, relatively inexpensive, simple to run, and has good documentation and parameters that are easily changed. Its drawbacks are that it models only single-compartment neurons and it cannot be easily modified.

Another program used in the same course was created by Dr. Chiel and a graduate student. It is written in C, runs on the Macintosh computer, and can be used at various levels of expertise: a simple demonstration program; a readily modifiable set of internal modules (by combining, for example, graphing routines with a subset of the ex-

Mr. Kent Reuber of Brandeis University describes the advantages of simulation software that allows science instructors to create illustrations of hands-on experiments while avoiding potentially costly and time-consuming software programming.

isting library routines to create a new simulation); or an extensible model. For example, a new ion channel type can be added by writing the library routines that describe it.

Case Western Reserve has also combined off-the-shelf and build-it-yourself technology. Students in a computational neuroscience seminar course were given robot kits developed at the Massachusetts Institute of Technology. The kits consisted of a microprocessor-based controller, Lego parts, motors, and sensors. The students also received background reading material and a graded series of exercises on sensors, motors, programming, and mechanical design. They worked in teams to build robots that solved real-world problems, such as collecting eggs while avoiding obstacles and other robots.

This hybrid approach was chosen to enhance students' ability to think critically and solve problems, especially in a team setting; apply engineering skills to the integrated design of autonomous agents that must function in the world; and understand more about essential issues faced by animals that need to survive in the real world.

Dr. Chiel's final words of advice were: "If you can find a good off-the-shelf solution, use it. If you build it yourself, it will take longer than you expect. If you want students to be able to use technology to solve novel problems, they need to be able to build it themselves."

Brandeis University

In some cases, said Mr. Reuber, neither off-the-shelf nor build-it-yourself software may be desirable. It may be difficult to obtain off-the-shelf software with the content desired by the instructor. On the other hand, developing software in conventional programming languages is time-consuming.

A possible compromise is the use of simulation software. These commercial software packages bridge the gap between off-the-shelf and build-it-yourself technology, require short development times, and are simple to maintain. Their open-ended framework and use of point-and-click technology helps students design and develop their own projects.

Many types of simulation software allow the instructor to create systems quickly and easily by using point-and-click techniques while the underlying physical laws, mathematical formulas, or differential equations are handled by the software. This allows instructors to build useful illustrations or hands-on experiments specific to their needs without the necessity of creating the complex underlying systems.

For example, simulation software such as Interactive Physics (by Knowledge Revolution, San Francisco) graphically allows instructors to draw physical systems containing masses, springs, rods, and so on, and initial conditions, while the program takes care of gravity, collisions, and friction. Students have the option to change the parameters and run the simulation again. A sufficiently general simulation software package can be used for a variety of purposes in a single course, reducing the number of programs that students and instructors must master.

Referring to the continuing debate over whether the DOS or Macintosh platform is to be preferred, Mr. Reuber noted that a promising technology called CHURP (common hardware surface platform), which may be available in about two years, may eliminate compatibility problems between IBM and Apple computer software.

University of Washington

The university's efforts to improve teaching through the use of appropriate technology began about five years ago, said Dr. Palka, with the purchase of videomicroscopy equipment and a set of computers for data acquisition.

Videomicroscopy makes teaching more efficient because instructors can demonstrate what the students should be looking for in their own preparations. A private activity (looking down a microscope) becomes a social one (watching a video screen). The group situation generates a deeper level of student involvement and discussion.

A course on karyotyping that previously involved taking photos and cutting and pasting them into appropriate configurations was modernized by storing high-resolution pictures on a computer. Students could easily move the pictures around after the computer did the cutting, pasting, and aligning. In a neurobiology course, the instructor put a collection of slides onto a compact disk and made the disk available to students.

Dr. John Palka of the University of Washington discusses new approaches in teaching undergraduate science, including "virtual instruments" that allow students to quickly learn techniques of instrument control and focus on key concepts of biology experiments.

The university originally purchased eight Macintosh computers equipped for data acquisition to replace oscilloscopes, chart recorders, and other traditional equipment in advanced physiology courses, Dr. Palka said. The data acquisition programs were written in LabView, a flexible system that creates virtual instruments whose controls are operated with mouse clicks.

The virtual instruments can be optimized for a particular experiment so that minimum student time is invested in learning instrumentation. For example, in an electrophysiology course, virtual instruments were constructed to measure membrane potential. By the end of a three-hour laboratory class, every group of students was measuring resting potentials, something they would not have been able to do without computers.

"Our guiding principle is maximum simplicity," said Dr. Palka. The use of virtual instruments has increased interest and enthusiasm among both students and faculty. The University of Washington, he concluded, views technology as a powerful ally in a teaching approach that is firmly rooted in firsthand experience. "We generally reject the view that computer exercises can replace wet labs."

Discussion took place within the context of the formal presentations.

Summary of Key Issues

Susan Henry, Ph.D. □ Orville Chapman, Ph.D. □ Sondra Lazarowitz, Ph.D.
Joseph G. Perpich, M.D., J.D.

Finding a Balance

Dr. Henry reviewed many of the salient issues that had been discussed at the meeting. One such issue was setting the proper balance between wet laboratories and virtual laboratories. The presentation by the University of California–San Diego showed that the two are mutually supporting tools. Virtual laboratories can be used not only to support student learning but also to enhance students' ability to get the most out of the laboratory experience and learn at their own pace.

Time and Talent

Another key issue was the significant amount of time invested by faculty and staff in developing computer-based educational materials. The development of materials that can be used as national models should be considered scholarship, Dr. Henry said.

Beyond the questions of providing rewards and release time to develop these materials, she added, are issues such as how to decide which projects to spend time and talent on, how to interest the most talented people in such work, and how to provide them with the time to do it. She noted that at her institution, Carnegie Mellon University, more faculty members than can be accommodated want release time to develop computer-based educational materials.

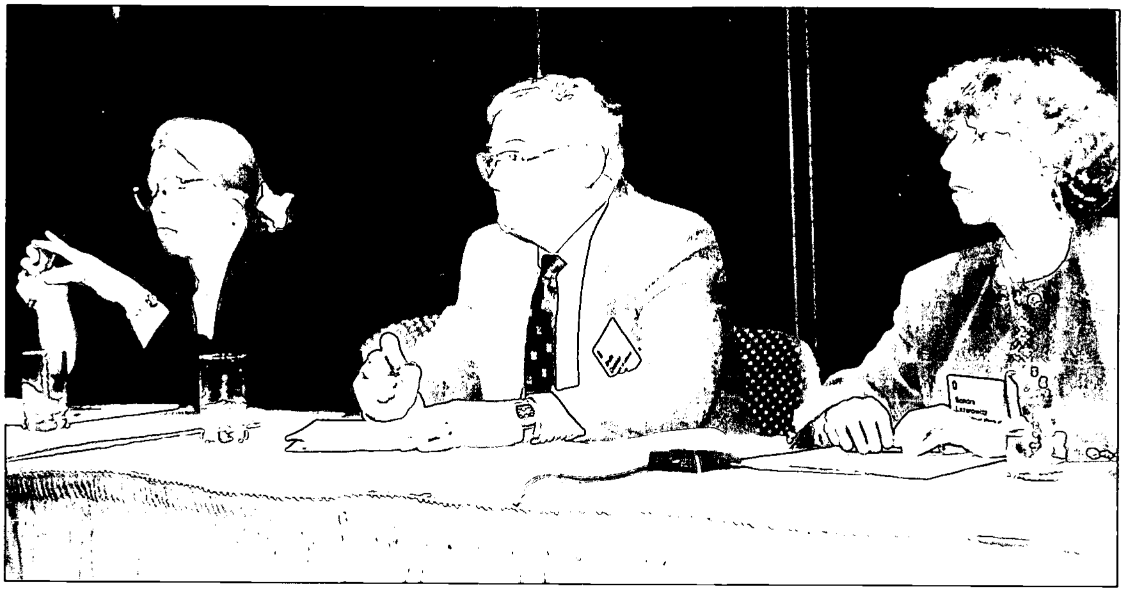
Assessment

Faculty have not yet grasped how to measure whether students are learning better as a result of computer-based activities, Dr. Henry said. She asked the Institute to provide opportunities for further discussion of assessment of educational technology.

She wondered if there was a danger that overreliance on educational technology would result in students losing the ability to struggle with problems. "If we make education amusing and not hard work, . . . will they lose the ability to search for things?"

Dr. Chapman observed that when evaluating new technology, "we must also evaluate how ineffective the lecture is as a means of learning." On the issue of virtual versus real laboratory experience, he said that there would always be a place for real laboratories. Assessments have shown, however, that students who use virtual laboratories use their time more effectively and have a better attitude toward science after completing the course. By contrast, students who use traditional lab-

Drs. Susan Henry, Orville Chapman, and Sondra Lazarowitz reply to program directors' questions during the final plenary review session.



oratories tend to have more negative attitudes afterward. In a constrained funding environment, Dr. Chapman added, virtual laboratories offer significant cost advantages.

Need for Investment

Drs. Chapman and Lazarowitz both emphasized the importance of university administrations making a sustained financial commitment to educational technology. Dr. Chapman noted that computer equipment quickly becomes obsolete and must be replaced every three to four years. He added that corporations invest more in technology than academic institutions. "Rice University puts 2 percent of its budget into educational technology. Corporate America is spending 5–6 percent."

Dr. Lazarowitz said that although investment in technology requires long-term planning, institutions are tied to annual budgets. In addition to sustained financial support, she added, technological support is also needed through education technology centers.

Empowerment

On the issue of faculty using technology, "many people don't adopt it because they don't know about it," Dr. Lazarowitz said. "We need to empower the participants. The technology allows us to create communities where communities could never exist. It expands and changes educational communities. It personalizes the learning environment."

A variety of solutions to common problems were presented during the meeting, Dr. Lazarowitz said. The message, she added, is that "one size doesn't fit all." She commented that if meeting participants would not think of ignoring advances in science, neither should they ignore advances in teaching and education.

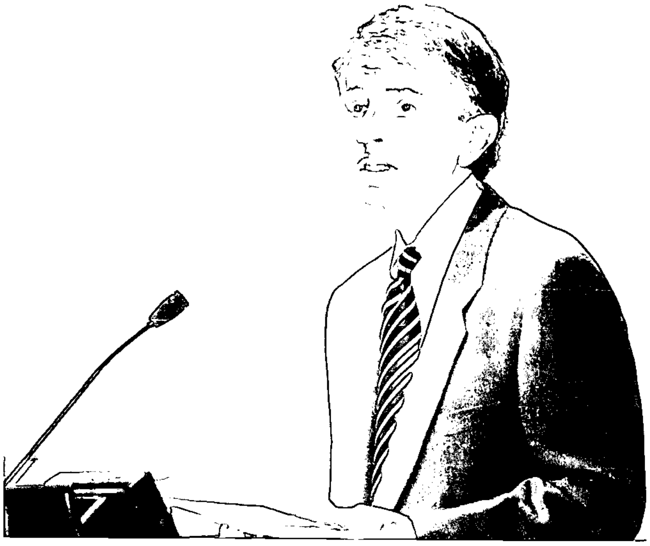
Discussion

Maintaining Vitality in Higher Education. Participants discussed strategies to ensure that financial constraints do not sap the vitality of higher education. Graduate students are one of the best ways to sustain and promote research, said Dr. Peter Bruns, Cornell University, and training grants are an effective device for recruiting the best students. He suggested that the Institute and other agencies that support graduate science education consider supporting training grants in addition to fellowships. Dr. Richard April, Colgate University, suggested that the Institute consider funding teaching fellowships that would attract to small colleges graduate students interested in teaching.

Dr. Frank Vellaccio, College of the Holy Cross, observed that in a world of dwindling financial resources, academic institutions' investment in educational technology must replace investment in something else. Dr. Henry said she hoped that these technologies would become standard tools that help institutions to work more efficiently. Ultimately, she added, they may replace some wet laboratories. Participants discussed whether institutional downsizing would have a greater impact on young or middle-aged faculty members.

Assessment of Computer-Based Learning Materials. Dr. Henry recounted a personal story to illustrate the dangers of excessive reliance on technology in education. The story involved an altercation between a customer who had received incorrect change and a sales clerk who refused to believe that a computer could be mistaken. "We are training students not to use common sense because they're reliant on the underlying technology," she said. "That doesn't mean you don't use the technology, but perhaps students need to learn how technology works."

Continuing assessment is crucial if an educator is to be clear in her goals, said Dr. Lazarowitz. She took issue with those who argue that computerized teaching materials should mimic the style of television "because that's what [students] want. I'm not here to give [students] what they want. I'm here to make a change in the way [they] look at the world."



During the final plenary session, Dr. Joseph G. Perpich comments on the impressive range of technologies presented over the course of the meeting and summarizes key points made by program directors.

Dr. Michael Gaines, University of Miami, agreed that educators must have goals but added that technology must be demonstrably effective if educators are to be convinced that it is a worthwhile investment. "The only assessment presented [at this meeting] was that it wasn't hurting, but it wasn't helping either." Dr. Chapman suggested that assessment should be the focus of the next program directors meeting.

Dr. Henry called on scientists to apply the same strict measures of analysis to the system of higher education that they use in their own research. "What makes a person learn can be measured," she said. "We need to invite experts who can tell us what is effective and how to measure it."

Concluding Remarks

In his concluding remarks, Dr. Joseph Perpich, HHMI Vice President for Grants and Special Programs, reviewed the principal themes that had framed the discussions during the meeting.

The intent of new technology is not merely to develop online books, he said, but to develop better learning skills. There is a need to accommodate different learning styles; some students may benefit more from technology than others.

Participants had raised the issues of assessment of technology, its impact on faculty and on the university, the challenges presented by financial constraints, the role of the university campus in an online world, and the importance of involvement in educational technology in promotion and tenure decisions. Other issues, including who has access to and who controls access to technology, who is responsible for quality control, and whether computers replace or enhance real laboratory experience, remain open questions.

Dr. Perpich reminded participants of the cabinet-maker analogy used by Dr. Hillel Chiel, Case Western Reserve University: A computer program can display pictures of hammers, nails, and wood, and it can even be used to design the cabinet, "but that doesn't mean the technology will enable you make the cabinet."

Dr. Perpich noted that much as the revolution in biology has bolstered research in the life sciences at colleges and universities, so too will the revolution in educational technology bolster undreamt-of possibilities in the value and impact of good teachers. People will truly become learners throughout life.

In his own college days, Dr. Perpich said, he had been impressed with an article by Robert Coles, "A Young Psychiatrist Looks at His Profession." Coles advocated bringing the benefits of the psychiatric revolution to underserved populations in rural and urban areas. Paraphrasing an observation by the writer Paul Bowles, Dr. Perpich said the Coles article was like a gong that had rung 30 years ago in his life and he could still hear its resonance. Our teachers and our mentors put the fire into us, he added, and inspire each generation of students to think the unthinkable and go boldly where no one has gone before.

Sessions I and II

Other Educational Technology

Sessions I and II

Beloit College

The BioQUEST Library

The BioQUEST Library is a compendium of computer-based tools, simulations, and textual materials that supports collaborative, research-like investigations in biology classrooms and laboratories. The library modules address topics across the bioscience curriculum, including issues in evolution, genetics, molecular biology, physiology, ecology, and—new this year—developmental biology and botany. The library has five major components:

The BioQUEST Core Collection is the heart of the library. The 10 modules in the core collection were selected through an intensive peer-review process based on extensive review, testing, and validation in actual classroom use.

Collection Candidates (seven this year) are modules that have passed the first stage of field review and are offered anew for final review and extended classroom testing.

First Review Folder modules (14 this year) have received initial favorable reviews from the editorial board and are offered for their first round of field review and classroom testing.

The Extended Learning Resources folder (a new offering this year) presents a variety of additional resources—multimedia reference materials, demonstration stacks, etc.—that provide collateral support for investigatory learning.

Support Material Archive is an additional diverse collection of freeware and shareware tools, data, and text resources selected for inclusion by the editorial board.

Modules are evaluated on their overall quality of design; the realism of their biological research models; the degree to which they support an open-ended, research-like investigative approach to teaching; and their usability by and effect on students. All library users are encouraged to participate in the review process.

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Bryn Mawr College

Serendip

"Serendip is a gathering place for people who suspect that life's instructions are always ambiguous and incomplete . . . a forum and a continually developing set of resources to support intellectual and social change in education—and in how one makes sense of life."

Combining brain research, computer science, and a deep interest in the implications of both for education in the broadest sense, Serendip is a World Wide Web site <http://serendip.brynmawr.edu> at Bryn Mawr College. Now a year old, Serendip is already an established resource in the area of brain and behavior, for students and teachers at all educational levels, as well as a continually evolving exploration of the potential of the Web to create a freer, richer, and more interactive intellectual community.

Serendip makes available information, exhibits, forum areas, and a host of links to related Web sites, but its primary objective is to provide a rich environment of experiences that encourage visitors to think more deeply about the underpinnings of their own and others' behavior. The important role the brain plays in creating one's picture of the world is highlighted by an interactive demonstration of phenomena associated with the blind spot of the eye. Considerations of selfishness and cooperation emerge from playing a version of the game Prisoner's Dilemma with Serendip.

A voyage to Serendip yields insights into the nature of creativity and its role in problem solving. A theme from that, Serendip(ity) itself, carries over into a consideration of free will and personal choice motivated by experiences with ambiguous figures.

The Serendip project was initiated by a group of Bryn Mawr College faculty members and alumnae. Free to develop as its name implies, Serendip has attracted valuable undergraduate participation and is increasingly playing an important role in computer education for undergraduates and for the college community generally. It may be a useful model of how participation in unfettered Web development can reciprocally benefit academic programs and the intellectual community.

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Carnegie Mellon University

Advanced Computing for Science Education

Certain aspects of scientific reasoning that are difficult for students to learn with traditional lecture and textbook materials may be facilitated by computer-based learning environments. Two examples are understanding complex time-varying processes and planning an investigation to discover the mechanisms of such processes. The Advanced Computing for Science Education (ACSE) project has designed, built, and assessed a multimedia science-learning environment to address the teaching of these skills.

The ACSE software system provides lesson authors with a structured document framework and a set of tools that facilitate the construction of science lessons containing text, still graphics, movies, and simulations. The system provides students with tools for navigating through the lesson, viewing movies, and manipulating and running the simulations.

In typical simulation-based learning systems, the program itself is hidden from the user. This is a natural choice because the science that is imbedded in that simulation is a very small portion of the overall program and is not organized in a manner that would be readily understood by the science student. A set of controls are provided that permit students to manipulate certain well-chosen variables and see the results.

ACSE is distinguished from typical systems by the way the simulation is integrated with other lesson contents. Selected pieces of the simulation are interspersed throughout the lesson similarly to the way mathematical formulas are used in a textbook. These small pieces of simulation are chosen because they describe the essential science that is embedded within the much larger program. The program elements are provided in the context of explanatory materials, and irrelevant details are hidden.

The student manipulates the simulation by directly modifying these program elements. A full-featured novice programming environment is provided to support this activity. Thus, the student is afforded the full expressive power of a programming language. This permits the student to investigate the simulation by making structural changes—those that involve modifying or replacing algorithms—in addition to the kinds of changes permitted in traditional simulation systems.

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Case Western Reserve University

HH–A Program to Simulate Branching Neurons

The software program HH was programmed by Mark Dimaline, a master's student advised by Drs. Randall Beer (Computer Engineering and Science) and Hillel Chiel. This program allows students to explore the importance of cell morphology in cell function. Using a simple graphical interface, they can construct complex branching structures and explore the propagation of electrical signals through this structure.

The program is written in C, runs on Macs, and can be used at three levels of expertise: as a simple demonstration program, as a readily modified set of internal modules (e.g., a new simulation can be constructed by combining graphing routines with a subset of the existing library routines, and as an extensible model (e.g., a new channel type can be added by writing the library routines that describe it).

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Hope College

Computers as Teaching Assistants

This technology can be done with the following minimum hardware: a Mac or PowerMac with QuickTime installed, an Apple QuickTake 100 or 150 digital camera, and the Microsoft PowerPoint program.

The instructor takes pictures of someone working in a laboratory—using sterile technique, dissecting an animal, or using a pH meter perhaps. Pictures are downloaded to the computer by using the software that comes with the QuickTake camera. A slide show with pictures and text describing the procedure is created with PowerPoint. A computer need be equipped only with the PowerPoint viewer program for a slide show to be loaded onto the hard drive. Students who want to learn a procedure can turn on the computer, load the viewer program, and pick the technique they wish to see. They not only get directions, but can view an example as well.

Seeing the pictures enables students to be sure they are using the right tools in the correct sequence. This technology allows students to work in the laboratory any time, regardless of whether an instructor is present, and still receive instruction on techniques.

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Iowa State University

Computers in Core Biology Teaching and Student Advising

Four years ago Iowa State made a commitment to redesign the core biology curriculum. Part of this effort was the application of technology to instruction. Six independent introductory courses in the biological sciences have been combined into a four-semester, integrated core sequence, with each new course having an accompanying laboratory. Today the core is in place, and numerous uses of technology have been developed and integrated into the biology sequence.

The Department of Biology acquired a dedicated server (DARWIN) to store lectures for student accessibility and to develop a large file of biological images. Our image-capture facility allows us to make a digital file of photographs, slides, and television images. With guidance from faculty, an in-house group produced 40 animations of biological concepts, customized for easy use in lectures and computer laboratories. The images are stored on a 2.4-gigabyte hard drive, which is connected to the DARWIN server. The university has a highly developed Ethernet capability that makes the server accessible, through this network, to over 1,000 biology core students, 24 hours a day, 7 days a week, and allows teaching staff, scattered in many different buildings, to use the resource material for lecture and laboratory development.

PowerBooks with PowerPoint software were purchased and loaned to biology instructors. An instructional technologist, hired with HHMI funding, locates resources, conducts workshops for faculty members, and handles technical problems. Faculty members can develop lectures in their offices by using visual images from the image bank and send the completed lectures to a built-in computer in the lecture auditorium. Because this computer is permanently networked, faculty members can also call up data from other servers or access the Internet during class. After classes, instructors download their lectures, including visual images, to DARWIN, where the material is then available to students and faculty via the Ethernet.

Use of computers is incorporated into laboratories to provide graphing programs for analyzing data, displaying simulations that model complex phenomena, and accessing the Internet. In the genetics section of the second-year lab, 200 students recently connected to GenBank and downloaded a sequence to help create a recombinant DNA molecule. During the laboratory they performed actual digests to prepare their gene for incorporation into a vector to transform yeast.

Computer use is now integrated into advising and retention efforts. The biology server carries a Hypercard file listing biological science faculty research areas, internships, summer research opportunities, and study-abroad programs. The biology adviser communicates with more than 100 advisees by e-mail, and the biology study groups keep a weekly journal via e-mail.

Preliminary input indicates that students feel computer presentations add interest to classes, aid their note taking, and are helpful in reviewing the lectures. Faculty members are more eager to teach in the introductory courses and report that "technology causes one to rethink the course."

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Kansas State University

Genetics Education Network

The Kansas State University Genetics Education Network (GENE) UVRisk software is an interactive simulation of the effects of solar ultraviolet (UV) light on humans and their environment designed for use by high school science students. The model is a simple approximation of the physics and biology of a complex system and is used to illustrate the underlying principles of the system.

The program itself incorporates several variable elements and an ultimate biological outcome. The user first selects a UV source, which includes choices of various lamps or solar radiation. If solar radiation is chosen, then the user selects the location, date, and time either for a city or for a known latitude and longitude. The user then selects different UV blockers and observes the predicted biological effects. During the program, any of the variables may be changed at any time for comparison of these biological effects. The user may compare a change in location, a change in time at the same location, a change in the UV source, changes in ozone concentrations, or changes from adding more UV blockers such as sunscreens.

A help menu is readily accessible and menu options are always provided. Data can be saved for future import into a spreadsheet, allowing the teacher to design classroom exercises using the spreadsheet program. UVRisk is easily run by novice computer students, is interactive, and enables students to explore changes in their environment.

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Michigan State University

BioScience Explorer 2.0

The BioScience Explorer 2.0 software is a CD-ROM containing three separate programs. The central feature is composed of 13 full-color animations of standard introductory topics, including oxidative phosphorylation, transcription, translation, and replication. These are intended to help students to think in terms of three-dimensional molecular structures and processes and not just words. Animations can be navigated by students at their own pace via interactive controls. An illustrated, animated glossary of clickable "hot" words can be accessed separately.

The second program consists of the multiple-choice questions from examinations for the introductory biology course, Cells and Molecules. This database of practice questions is in an interactive format in which each possible answer is associated with an explanation of why that choice is correct or incorrect.

The third program is a simulation for studying population genetics. It includes Hardy-Weinberg law exercises and violations of the various assumptions of the Hardy-Weinberg law, including natural selection.

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Oklahoma State University

Teaching Science Using the World Wide Web

Eight two-year colleges participate in Oklahoma Partners for Biological Sciences (OPBS) with Oklahoma State University (OSU). To enhance the numbers and preparedness of students transferring from these schools into biological sciences programs at OSU, the schools are being assisted in developing Internet capability, and current technologies are being made available to them.

Teaching tools have been developed by using resources available on the World Wide Web, and the colleges' computers have been equipped with RasMol for PC molecular viewing software. Disk libraries of large and small molecules are used in teaching. RasMol can image large molecules such as DNA and proteins through the use of crystallographic data downloaded from databases such as the Brookhaven Protein Database and the Human Genome Database. A library of small molecules has been developed using a variety of resources.

As the colleges continue to gain Internet access (three of the eight already have it), they will be able to link to the Department of Biochemistry home pages <http://bmb-fs1.biochem.okstate.edu/OPBS/OPBSHomepage.html>. Links on the home pages will connect to useful Web sites, such as the large-molecule databases, Medline, and safety information. Colleges will be able to link to the OSU library by using Telnet, thus giving them the resources of a research university library to assist in developing research projects. Also accessible will be the virtual-laboratory tutorials developed at OSU for introductory biology courses.

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Texas A&M University

Use of the World Wide Web in a Freshman-Level Biochemistry Class

Over the past several years, the university's freshman-level course for entering majors (more than 100 students per year), Horizons in Biological Chemistry, has increasingly made use of electronic resources. Lecture material is reinforced with PowerPoint presentations. During the first week of class, students are required to open their computer accounts, communicate electronically with the instructor, and access the university's student information management system to validate their local and permanent addresses.

By fall 1995, all resource material was available to students exclusively through electronic media, primarily via the World Wide Web. In addition, students now are able to communicate directly with instructors and other students through e-mail and electronic conferencing. Resources on the Web include the syllabus, the text, assignments, prior examinations, tutorials, lecture presentations, as well as other Internet resources.

Feedback shows that students overwhelmingly support these added features of the course. The address for the course home page is <http://acs.tamu.edu/~EAF1720/BICH107.HTML>.

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University of California–San Diego

An Interactive Lab Manual: Improving Laboratory Instruction with Multimedia

Drs. Wienhausen and Sawrey, in collaboration with Maria DelCasino (a graphic artist) and Scott Kelley (a programmer), have developed an interactive lab manual for a wet laboratory, Biochemical Techniques, to improve student preparation and cognition. The courseware makes the use of laboratory time more efficient, aids understanding of the lab processes, and acts as a self-paced tutorial.

Students can review an experiment, learn more about the main technique being used, or practice the math skills needed for the laboratory exercise. On-screen information, screen features, and overall layout were designed to take into account pedagogical and cognitive implications of the learning process: on-screen information is presented to the students nonlinearly; numerous branching points, layers, and thought-provoking questions force students to become actively involved in the learning process.

Photos, movies, illustrations, and animation help students to visualize the experimental steps and the equipment as well as the events happening on the molecular level. Simulations allow students to practice setting up and using equipment. Built into the modules is a system that allows electronic communication between instructor and students as well as online library research.

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University of Illinois at Urbana-Champaign

BioCalc, a Computer Laboratory–Based Approach to Learning Calculus

In 1993, Dr. Sondra Lazarowitz of the Department of Microbiology and Drs. Jerry Uhl and Horatio Porta of the Department of Mathematics created BioCalc, introductory calculus for life science majors. A computer-based laboratory approach to teaching, BioCalc is based on Calculus&Mathematica, a program created by Drs. Uhl and Porta in collaboration with Dr. Bill Davis of Ohio State University. It uses Mathematica as the language of mathematics to allow students to focus on learning concepts. Students work cooperatively in small groups, progress through the material at their own pace, and demonstrate their knowledge in several formats (written, oral, and graphical). Because problem sets are based on actual life-science problems, students see the relevance to their career goals.

BioCalc has been extraordinarily successful. Students master advanced calculus usually reserved for senior-level math classes. Many BioCalc students choose to enroll in more advanced math courses because of their positive experiences in BioCalc; these students have succeeded in traditional mathematics courses as well as those based on Mathematica.

To understand how Calculus&Mathematica succeeds at engaging students in a true intuitive understanding of mathematics, one has to actually use the program on the computer. Without hands-on experience, people have a hard time envisioning how it works.

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University of Iowa

Assessing Computer Learning in Introductory Courses

Simulations as Direct Teaching Tools in the Laboratory Portion of an Introductory Course. For the past eight years, four locally developed simulations have been used as aids in the teaching laboratory of the introductory course. These programs simulate the nerve impulse (Action Potential), population growth (GrowPlot), population genetics (GenePlot), and predator-prey interactions (WaTor). Unlike most comparable software, where the student uses the program in a computer room interactively but is minimally supervised, these simulations were designed to be used by every student (working in groups of two or three) in a structured laboratory with teaching-assistant supervision. Each program has a specific set of written instructions and questions to be answered in the student's laboratory text.

At the end of the semester, students are asked whether they feel that the computers and simulations helped in their understanding of the principles of that laboratory. Typically, about 70 percent of the students find the simulations helpful, although an appreciable percentage (25 percent) would like more time to interact with the programs. For this reason, the programs were translated to Macintosh format and incorporated into our newly completed Computer-Assisted Laboratory for Undergraduate Biology (the CLUB). Evaluation of the simulations is continuing in this new venue.

Computer-Assisted Lecture Presentations in Introductory Courses. A portion of the CLUB is set up as an authoring station where faculty members can create computer-assisted presentations and classroom or laboratory exercises. Faculty members have been slow to use this facility; results from two or three pioneers make it clear that students differ in their reactions to use of the technology.

One professor has used computer-assisted presentations frequently in the lecture section of an advanced animal physiology course. Evaluation of this use has not been extensive or systematic, but students commented that the presentations speeded up the pace of the lecture so much that they failed to absorb the material, even though copies of the presentation files were available in the CLUB and over the campus network. Another professor used computer-assisted presentations in a small (fewer than 50 students) neurobiology course for students not majoring in science.

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University of Oregon

Demography 2.0

Why are human populations in Africa growing so rapidly, even though life expectancy is shorter than in most other parts of the world? Why do rapidly growing populations have such a large proportion of children? Why is the population of China still growing, even though the Chinese government is enforcing a one-child-per-couple population policy?

These are samples of the questions that can be addressed by Demography, a computer-simulation program developed by the biology software laboratory at the University of Oregon. Demography simulated exponential growth in age-structured populations. By manipulating values for age-specific mortality rates, fertility rates, and initial population characteristics and using the simulation to see how population characteristics change over time, users of Demography can investigate important questions in population biology, develop a deeper understanding of fundamental population concepts, and explore issues related to population policy.

Population issues, ranging from the human population to populations of pests, diseases, or endangered species, illustrate the critical links between biology, personal decision making, and public policy. How people and nations choose to confront these problems has had and will continue to have a major impact on our planet and on the quality of our lives. The Demography program allows students to investigate the possible consequences of different population or conservation policies, illustrating the important role that scientific modeling can play in decision making.

The program is designed to make it easy to creatively explore and experiment. A key feature of Demography is the direct-manipulation interface that allows users to rapidly and intuitively alter population characteristics by editing graphs and instantaneously see the effects of those alterations. Demography 2.0 runs on Macintosh computers and is available on the 1995 BioQUEST CD-ROM.

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Colby College

Information Technology in the Molecular Life Sciences

Molecular mechanics and dynamics, molecular orbital calculations, and database searches on the Internet are included as routine tools in Colby College's teaching and research program.

In the new HHMI-supported Bimolecular Structure course, students use molecular modeling to help understand protein structure. Students download structures from the Brookhaven Protein Database. They add hydrogens, determine the minimum energy structure, and study enzyme substrate interactions.

Students are encouraged to use the Internet to access structure databases, including the Klotho database at Washington University, the National Institutes of Health Drug Bank, and the Electronic Conference on Trends in Organic Chemistry proceedings. Students are given instructions for using RasMol as a Netscape helper application for automatic structure display. They are also encouraged to take advantage of the ExPASy and Swiss-Prot protein databases as well as online searches of the National Library of Medicine GenBank.

Project-oriented laboratory exercises throughout the curriculum reinforce the use of these information technologies. For example, CD-ROM–based searches of *Applied Science and Technology Abstracts* and the *Biological and Agricultural Abstracts* are a part of the introductory biology and chemistry courses, and online searching of *Chemical Abstracts* using STNexpress is included in the general chemistry course.

Use of information technology has led to the development of a program in computer-aided molecular design (CAMD), a combination of computational chemistry and information technology tools that aid in the discovery of new and useful compounds. CAMD is a natural bridge between biology and chemistry that will be incorporated throughout the college's science curriculum to teach students how to design and test new compounds for biological activity.

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*Not demonstrated during conference sessions

Colorado College

In the summer science program, first-year students are taught to use writing and analysis software (Windows 3.1 and Microsoft Office) to facilitate their performance in science classes. Students master data presentation in various table and chart forms and construct models using computer graphics to enhance their written presentations. In addition, students are taught basic math and analysis skills needed for introductory chemistry courses.

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College of the Holy Cross

Chemistry Review Modules

The college's chemistry department is developing software review modules to assist the education of science majors, premedical students, and high school chemistry teachers. The modules are written with the ToolBook software package, which creates object-oriented programs that can be navigated with a mouse.

The need to develop these modules arises from the chemistry department's method of teaching chemistry—the Discovery Curriculum. This approach introduces students to chemistry by involving them in the process. The specialized laboratory experiments developed at Holy Cross form the heart of the curriculum. Because no commercial textbooks or other review resources were available to the students, this specialized review software was developed to meet students' needs.

Students use the modules outside of class to review material from just-completed experiments. These interactive modules incorporate text, photographs, video, and animation and have the potential to include audio information. Some sections contain questions that must be answered correctly before students can move on.

The programs are installed on computers throughout the department and will soon be incorporated in the college's multimedia resource center. Seven modules—covering experiments in general and organic chemistry in particular—have been completed, including modules for the Ponnios experiment, visible spectroscopy, descriptive chemistry, and electrophilic aromatic substitution. Other modules are being developed.

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Morehouse College

Software Program: Abacus Concepts, StatView

StatView is a full-featured statistical data-analysis program that runs on Apple Macintosh computers. This program is used in the ecology laboratory and in the biostatistics course. An intuitive graphical interface, spreadsheet data entry formats, and straightforward command windows make this program very easy for undergraduates to use, even those with only a limited understanding of statistical theory.

In the ecology laboratory, students enter data collected from their experiments, perform simple statistical analyses, and prepare graphs and tables—all with StatView. Students in the Biostatistics course use the program to analyze prepared data sets to learn the appropriate use of statistical tests for hypothesis testing. In both courses, lectures and discussions on the use of statistical tests occur before students use the computers. Such discussions are necessary for undergraduates to be able to apply appropriate tests and correctly interpret test results.

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National Research Council

The CUSE Library of Undergraduate Science Education Information

The National Research Council's Committee on Undergraduate Science Education (CUSE) has developed an extensive electronic database for use by NRC staff. With HHMI support, CUSE will make this database available to the scientific and higher education communities on the Internet during the next four years. The database focuses on many aspects of undergraduate science education, including model undergraduate courses and laboratories, information about higher education organizations and publications involved in science education reform, and summaries of important articles dealing with science education that are unfamiliar to most academic scientists. More than 800 records that have been compiled for this Lotus Notes database will be placed on the Internet and made available to science educators and researchers through the World Wide Web (Netscape and Mosaic) <http://www2.nas.edu/cusehome/index.html>, gopher, and FTP interfaces.

Using this database, HHMI program directors and staff will enjoy more comprehensive, nationwide connections with scientists, educators, and programs outside the HHMI network. By electronically linking the CUSE and HHMI computer servers, CUSE will offer the larger higher education community much broader access to HHMI's successful programs and directly involve HHMI staff and program directors in national efforts to bring about meaningful change. HHMI's support of and collaboration with CUSE also will focus the discussion of undergraduate science and mathematics education at the highest levels of leadership more effectively than either initiative could achieve alone.

The database will enable HHMI grantees to share the talents, expertise, and programs they have developed with others in the science education community who have not been associated with the Institute's undergraduate program. Creative solutions to the problems that are of interest to HHMI also have been developed by other groups (e.g., Project Kaleidoscope). Current technology can allow users to move from one database to another transparently while enabling each sponsoring organization to maintain and update the information in its own database. Providing easy access to information already collected by CUSE, the NRC, Project RISE, and that supplied by HHMI grantee institutions and other national projects in an interactive database network would be a resource of incomparable value for thousands of faculty members, precollege teachers, administrators, and state and national policymakers.

In addition to collaborating with the organizers of HHMI's Web site, CUSE staff will work with other agencies and organizations to allow users of the CUSE database to connect to other database sites related to science education such as

- *Journal of Chemical Education* gopher at the University of Wisconsin
- Project Kaleidoscope gopher at Augsburg College
- National Center for Education Statistics gopher
- National Science Foundation's STIS gopher
- Department of Education's ERIC gopher

HHMI will support this project for an initial period of four years. During that time, CUSE staff will monitor usage of the database and make its availability known to the higher education community through announcements in professional journals and Internet user groups. At the end of this period, the committee will decide how the database might be expanded or reformatted to take advantage of new information technologies.

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Rice University

XRayView: A Teaching Aid for X-Ray Crystallography

A software package, XRayView, uses interactive computer graphics to introduce basic concepts of x-ray diffraction by crystals, including the reciprocal lattice, the Ewald sphere construction, Laue cones, the wavelength dependence of the reciprocal lattice, primitive and centered lattices and systematic extinctions, rotation photography, Laue photography, space group determination and Laue group symmetry, and the alignment of crystals by examination of reciprocal space. XRayView is designed to be user friendly and has motif-style pull-down menus to control the program. The program is written in C using interactive, object-oriented paradigms. Although supported only on Silicon Graphics, Inc. computers, it is expected that as Silicon Graphics supports its OpenG1 graphics language on more platforms, the program will be available more widely. Many of the experiences of using real x-ray diffraction equipment to examine crystalline diffraction can be simulated. Exercises are available online to guide the users through many typical x-ray diffraction experiments. The program is used in an upper-level laboratory module in biophysical methods.

XRayView is available free to universities and other educational institutions and by special arrangement to other organizations. Executables of the program are available via the World Wide Web at <http://www-bioc.rice.edu/XRayView>. Development of the program was supported by the W. M. Keck Foundation, Rice University, and HHMI.

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Saint Olaf College

Software for Premedical Education

A course on the uses of computers in the health-related professions is offered during the interim period between semesters to approximately 20 students, most of whom are premedical students majoring in chemistry, biology, or economics. The central focus of the course is the laboratory, where students work with exercises and tutorials that demonstrate how computers are used for telecommunication, medical imaging, databases, and other applications.

Access to the World Wide Web and to A.D.A.M. software has permitted student projects to become more complex and dependent on networking. This course enables undergraduates to become familiar with resources that will be invaluable in their future careers.

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University of Cincinnati

Multimedia Applications for Inquiry-Based Laboratory Exercises in Biology

Computer-assisted multimedia applications can be used effectively to increase student learning, interest, and retention in undergraduate courses. Multimedia's dynamic mixture of full-motion video, still images, graphics, text animations, and sounds from a variety of sources is an excellent way to convey the concepts, processes, and excitement of science to undergraduates. It is effective both in lecture classes, where it is used as a presentation tool, and in learning laboratories, where students are able to engage in self-paced interactive learning at multimedia workstations.

A powerful multimedia development and authoring workstation and server have been built in the biology department's multimedia development laboratory. The workstation is composed of two networked 90 MHz Pentium computers with 32 megabytes of RAM each, sharing 3 gigabytes of internal hard drive space in addition to a shared 9-gigabyte fast SCSI A/V external hard drive. The computers are fitted with video and audio capture and overlay boards into which feed flatbed and slide scanners, a videomicroscope, laser-disk and VHS playback machines, a TV link, and an Ethernet connection to the World Wide Web. Podium for Windows (a multimedia presentation manager), Quest 5.0 for Windows (a multimedia authoring package), and Adobe Photoshop 3.0 are used in addition to Windows 95 and Microsoft Office 95.

Over the past three years, numerous seminars, workshops, and demonstrations have been held on how to set up and use multimedia applications in the classroom. These presentations always produce a great deal of excitement and enthusiasm among faculty members who attend them. However, enthusiasm soon fades as individual faculty members come up against the same old problem—lack of multimedia materials and resources. This deficiency is particularly acute in community colleges, high schools, and other institutions where access to high-end digitization technology is limited or nonexistent. An obvious solution to the problem is sharing. In the near future, the Web will be used to help share multimedia resources. Biology teachers everywhere will be able to access the university server and download video and audio clips, still images, graphics, and animations for use in their classes. (Progress can be monitored at <http://ucaswww.mcm.uc.edu/> or <http://www.uc.edu/>.

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Computerized Physiology Lab

Complete integration of computer technology into all aspects of laboratory instruction in the physiology course is a major objective of curricular innovations in the Department of Biological Sciences. In both the lower-level anatomy and physiology laboratories and the advanced vertebrate physiology laboratories, groups of three or four students share a computer station interfaced with appropriate data-collecting equipment. Students thus become comfortable with the use of computers for everything from simple word processing to sophisticated data gathering and processing.

In the anatomy and physiology laboratories, MacLab interfaces and software are used to study muscle contractions, electrocardiograms, and respiratory functions. The Macintosh computers are also used to run a variety of simulations, including the Human Physiology Series (by J. M. Yochim and Y. J. Dori), Computer Rabbit (by G. Hellekant and A. Tsang), and MacDiet (by S. McKinney). Assignment outlines for all laboratories and outlines of corresponding lectures are stored on the computer hard disk and are always available to students.

The advanced vertebrate physiology laboratories are built around IBM-compatible computers interfaced with the Sable Teaching and Learning System transducers and software. Experiments on muscle contraction, nerve excitation, electrocardiograms, oxygen consumption, and respiratory movements are carried out with this equipment. Simulation programs—Mechanical Properties of Active Muscle and the Membrane Potential Problem Solver (both by R. A. Meiss)—provide excellent interactive studies of neurophysiological principles. Data analysis and visualization are emphasized in this course; graphing and the interpretation of graphs are central to all assignments. Laboratory protocols are stored in the computer's memory, and each student group has a private folder where data can be kept in various stages of refinement. Some groups use their computer station for all stages of the laboratory experience, from receiving the initial assignment through printing out of the final report.

The strategy of this computer use is to increase the students' productivity and enjoyment and to give them the confidence to deal with the pervasive use of computers that they will encounter in their ongoing biomedical careers.

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The undergraduate program directors meetings bring together individuals from a wide variety of institutions, ranging from small liberal arts colleges to large research universities. Program directors value this opportunity to exchange information and experiences with colleagues from different institutions.

Program directors had requested that time be set aside during the meeting for discussion of common issues with colleagues from like institutions. As a result, three concurrent resource group meetings were added to the agenda in 1995.

Each group included institutions within one of the categories of the Carnegie Foundation for the Advancement of Teaching. Program directors developed their own agendas for these meetings.

Comprehensive Colleges and Universities

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Co-Moderator
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Manhattan College

Participants briefly described the degrees offered by their institutions. Of the eight institutions represented at the resource group meeting, only Manhattan College and Mississippi College were private; the rest were publicly supported.

Student Diversity. Comprehensive institutions are among the most diverse in ethnic and gender representation, and this diversity is reflected in their biological sciences departments. At San Diego State University, for example, 46 percent of the students are members of ethnic minorities and over 50 percent are female. These populations are commuting students who must work long hours to finance their education. At Mississippi College, more than 80 percent of the students receive financial aid.

Resource Issues. Institutional resource constraints can restrict the development of courses at the upper-division level. Legislators in some states are not supportive of teaching initiatives and often impose restrictions on university purchases. Some departments supplement their resources by charging minimal laboratory fees (about $10). However, some state institutions are prohibited from charging such fees.

Participants discussed the importance of taking equipment obsolescence into account in departmental financial planning. Equipment leasing may be a viable alternative to purchasing. Most participants said that at their institutions all faculty members have computers on their desks. As technology costs increase, it becomes more important for universities to devise focused plans to establish and finance computer laboratories. The privatization of software will stress limited budgets. Nonetheless, a wide array of users and user programs are needed.

Faculty Response to New Educational Technologies. Participants agreed that many faculty members still need to be convinced of the benefits of new educational technologies. They discussed ways of persuading the skeptics of both the need for and the rewards to be gained by using the new technology. Most participants agreed that the instructional manuals often lack explicit directions and are generally not user friendly. Multimedia specialists and user groups are important resources to facilitate faculty training in the use of new educational technologies.

The issue of how institutional administration and promotion/ tenure committees regard the new technologies with respect to faculty development was also discussed. Most participants agreed that promotion and tenure committees at comprehensive colleges and universities tend not to give faculty members credit for implementing innovative approaches to teaching. It was suggested that a junior faculty member whose revolutionary computer program influences large numbers of educators and students is just as productive as one who publishes a research article.

Relationship with Community Colleges. A brief discussion focused on the role of community colleges as a source of qualified students for comprehensive institutions. Many participants agreed on the importance of broadening and strengthening relationships with community colleges and of basing these relationships on mutual trust and respect.

Liberal Arts Colleges

Moderator
David L. Beveridge, Ph.D.
Wesleyan University

Co-Moderator
Ruth E. Reed, Ph.D.
Juniata College

Approaches to Cooperative Learning. Participants provided examples of approaches to active and cooperative or group learning. One participant said that a colleague at her institution gives exams that consist of individual work followed by work in groups of three and work by the entire class. Another participant has students work together for the last 15 minutes of class, which gives them an opportunity for discussion. One professor includes a group discussion period in the middle of his lectures. He said he has found that through group learning he can present more challenging problem sets.

To encourage cooperative learning, participants recommended that explicit links be developed between courses. For example, students from two distinct courses (such as physiology or comparative vertebrate anatomy and cell biology) can collaborate on projects. A Harvard Business School cooperative learning course for faculty called Education for Judgment was recommended. There was a discussion about bibliographies on cooperative learning and its assessment. A participant from the National Research Council described a handbook and video entitled *Science Teaching Reconsidered*, which NRC was field-testing and expected to publish in the fall of 1996.

Finding Resources to Fund Science Programs. The importance of involving faculty and administrators in development activities was acknowledged. Some participants recommended that institutions develop a five-year plan to include all aspects of the resources needed, such as facilities and curricula. Such advance planning gives administrators time to consider funding sources.

The discussion then focused on the demands that educational technology places on resources. Although science appears to be a "black hole" in this respect, one participant observed that other disciplines such as foreign languages and art history now incorporate educational technology in their courses. Thus, educational technology is seen as an institutional need rather than as a science department need.

Bridging the Gap Between Science and the Liberal Arts. One institution has earmarked funds for faculty to develop cross-disciplinary teaching approaches in the humanities. It was suggested that the cognitive sciences might be another field of study that is amenable to interdisciplinary approaches. Interdisciplinary teaching and learning centers are another way to bridge the gap. At Wellesley College, faculty "shop talk" lunches, student mentoring, and cross-departmental senior-junior faculty partnerships provide opportunities for cross-disciplinary exchange.

Participants discussed an approach suggested by science education consultant Sheila Tobias, which involves bringing liberal arts and science faculty into each others' classrooms to observe and critique each others' learning environments as a prelude to moving both cultures toward the principles of a general education. Team teaching is another approach used by liberal arts institutions to foster interdisciplinary learning.

Impact of Educational Technology. Concern was expressed about whether educational technology would affect the hands-on, personalized teaching style that is often characteristic of small institutions. An alternative view was that technology is not depersonalizing and that it increases the importance of faculty.

Technology Resources. The Internet Users Group of the American Association of Higher Education, which distributes information and conducts national round tables on educational technology and technology policy issues, is a potentially important resource. At Wesleyan University, students enrolled in a writing course have access to papers on a World Wide Web home page, an "electronic literary salon," through which they can communicate with each other. The Mendel Web home page, a virtual classroom, may also be a useful resource.

Learning Styles. Participants discussed how students learn best, the importance of note-taking, and whether students listen more if they take fewer notes or if note-taking helps some students to focus on details. For students who are tactile learners, writing an outline or drawing structures is critical to learning. More important than any learning style, participants agreed, is that students need to be active participants to learn effectively; otherwise, they feel ambivalent about the information being presented.

Research and Doctorate-Granting Universities

Moderator
Kathryn G. Vogel, Ph.D.
University of New Mexico

Co-Moderator
Joseph H. Neale, Ph.D.
Georgetown University

Rewarding Teaching and Scholarship. Participants said that institutions sometimes find it difficult to objectively evaluate the contributions of individual faculty members to the institution's teaching and scholarship. A solution was offered that involves setting weighted standards for teaching and research. To operate effectively, such a system requires a proactive department chair to reinforce and encourage individual faculty members and maintain morale. The chair must also ensure that these measures are taken into account in the allocation of faculty responsibilities (such as teaching loads) and in the distribution of resources (such as research space and merit pay).

Participants commented that if faculty members' ratings for scholarship were graphed on a scale of 0 to 100, the resulting distribution was likely to cover the spectrum. By contrast, teaching ratings for these same individuals would tend to be clustered about the middle of the curve, suggesting that teaching is seen subjectively as good or poor but not evaluated on a full objective scale. Peer and student reviews of teaching were suggested as a remedy for this, within a system that uses written standards and goals. Together with multiple peer visits to evaluate teaching and a standing committee to finalize the analysis, teaching evaluations could provide a more appropriate range of merit scores.

The academic dossier was proposed as a successful method of balancing the evaluation of teaching and scholarship. Under this system, each faculty member assembles a teaching, scholarship, and service portfolio for the previous year; provides documentation and a rationale for conclusions about performance; and proposes goals for future years. Portfolios are evaluated by a peer committee in much the same way that an NIH study section reviews and rates research grants. To be effective, such a system requires that reasonable goals be set and documented so that tenure and promotion reviews can be approached objectively. Long-term documentation helps to promote realistic expectations and reduce feelings of disappointment. For example, it might be inappropriate for an untenured junior faculty member to strive for perfect ratings in teaching because this would imply that too much time was being taken from the pursuit of scholarship and that goals in that area were less likely to be met.

It was noted that teaching provides scholarship opportunities, a perspective that may be useful in obtaining greater balance in the teaching/scholarship relationship in merit and promotion evaluations. Discussion focused on whether tenure could be granted for scholarship based on or derived from teaching. One participant said that in his department the principal criteria for tenure were positive teaching evaluations by students and peers and receipt and renewal of a major research grant during the pretenure interval.

Another participant suggested that a distinction be made between promotion with tenure to associate professor and to full professor. In the latter case, evaluation on the basis of teaching alone might be valid in some circumstances. However, others said that this might be perceived as diminishing the achievements of faculty who obtained full professorship on the basis of both scholarship and teaching. Participants also wondered whether, since associate professors tend to remain in their positions for fewer years after the traditional retirement age, promotions to full professor on the basis of teaching alone would fill the tenured faculty ranks with individuals who had seniority but were not active in research. Such a consequence might inappropriately encumber a department's research and graduate programs.

Telephone interviews with graduates several years out of the university were suggested as an alternative means of evaluating teaching. This kind of outcome assessment could be designed to obtain retrospective evaluations of faculty members as well as evaluations of the extent to which a program had prepared students for professional life. Sample size and objectivity would be important factors in faculty merit evaluations.

It was argued that changes in the merit-pay system could be an effective means of rewarding both teaching and scholarship while recognizing individual strengths and weaknesses. Implicit in this approach is an increase in teaching responsibilities as faculty elect to have a greater portion of their evaluation derive from teaching. It was noted that declining involvement in research carries its own economic disincentive, the loss of summer salary.

Impact of Undergraduate Research on Faculty. Participants observed that success in bringing undergraduates into the laboratory often stimulates demand from both students and administrators. A suggested response to the problem of failure to obtain teaching credit for informal mentoring was the establishment of for-credit tutorial courses, so that mentoring of student research is recognized through student registration and tuition charges. It was noted that mentoring two doctoral students can compare in terms of workload to teaching a course to two dozen or more undergraduates. Increasing student demand for research tutorial opportunities comparable to those obtained by undergraduate students in HHMI-supported initiatives is placing a growing burden on faculties that are not increasing in size, participants said. At some institutions, medical center faculty are very interested in undergraduate education and provide many opportunities for research mentorship. Such faculty should be considered a potential resource to relieve pressure on undergraduate science faculty.

Participants noted that bringing new undergraduates into the research laboratory can be costly in terms of efficient use of faculty time and research resources. One option is to bring new students into the laboratory in groups. Courses with strong, research method–oriented laboratory components were seen as important in preparing undergraduates for the laboratory experience.

Changing Attitudes Toward Scholarship. Finally, it was noted that the core business of universities is education. Research can be viewed as too unfocused and too costly by government agencies and parents who are paying the nonendowed costs of university operation. Current trends indicate that universities may be called upon to become more efficient in the delivery of education in all areas, including the sciences. Participants suggested that society is less interested in paying the costs of scholarship.

They discussed alternatives to government funding and whether there are more efficient ways of making the discoveries that lead to synthetic fabrics, pharmaceuticals, polio vaccines, diagnosis of malignancies, and identification of the genes responsible for progressively debilitating, gene-related human disorders.

Appendices

Attendees, Program Directors Meeting, October 25–27, 1995

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Dunham Beldon Jr. Professor of Geology
Colgate Universiity

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Reed College

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Undergraduate Biological Sciences Education Program—1988 Awards

Allegheny College, Meadville, Pennsylvania	$900,000
Amherst College, Amherst, Massachusetts	500,000
Bryn Mawr College, Bryn Mawr, Pennsylvania	800,000
Bucknell University, Lewisburg, Pennsylvania	700,000
Carleton College, Northfield, Minnesota	800,000
Clark Atlanta University, Atlanta, Georgia	700,000
College of Wooster, Wooster, Ohio	1,000,000
Colorado College, Colorado Springs, Colorado	800,000
Davidson College, Davidson, North Carolina	700,000
DePauw University, Greencastle, Indiana	600,000
Dillard University, New Orleans, Louisiana	400,000
Earlham College, Richmond, Indiana	750,000
Franklin & Marshall College, Lancaster, Pennsylvania	400,000
Grinnell College, Grinnell, Iowa	400,000
Hampshire College, Amherst, Massachusetts	400,000
Hampton University, Hampton, Virginia	600,000
Haverford College, Haverford, Pennsylvania	1,200,000
Howard University, Washington, D.C.	900,000
Kenyon College, Gambier, Ohio	500,000
Lincoln University, Lincoln University, Pennsylvania	700,000
Macalester College, Saint Paul, Minnesota	800,000
Marlboro College, Marlboro, Vermont	400,000
Middlebury College, Middlebury, Vermont	400,000
Millsaps College, Jackson, Mississippi	600,000
Morehouse College, Atlanta, Georgia	400,000
Morgan State University, Baltimore, Maryland	400,000
Mount Holyoke College, South Hadley, Massachusetts	400,000
Oakwood College, Huntsville, Alabama	400,000
Oberlin College, Oberlin, Ohio	900,000
Occidental College, Los Angeles, California	500,000
Pomona College, Claremont, California	500,000
Rhodes College, Memphis, Tennessee	700,000
Saint Olaf College, Northfield, Minnesota	600,000
Smith College, Northampton, Massachusetts	400,000
Swarthmore College, Swarthmore, Pennsylvania	900,000
Tuskegee University, Tuskegee, Alabama	900,000
Union College, Schenectady, New York	900,000
Vassar College, Poughkeepsie, New York	700,000
Wabash College, Crawfordsville, Indiana	900,000
Wake Forest University, Winston-Salem, North Carolina	800,000
Wellesley College, Wellesley, Massachusetts	750,000
Wesleyan University, Middletown, Connecticut	1,200,000
Whitman College, Walla Walla, Washington	400,000
Xavier University of Louisiana, New Orleans, Louisiana	1,800,000
Total	**$30,400,000**

Undergraduate Biological Sciences Education Program—1989 Awards

Brown University
Providence, Rhode Island $1,000,000

Carnegie Mellon University
Pittsburgh, Pennsylvania 1,200,000

Case Western Reserve University
Cleveland, Ohio 1,200,000

City University of New York City College 1,400,000

College of William and Mary
Williamsburg, Virginia 1,000,000

Colorado State University
Fort Collins, Colorado 1,500,000

Columbia University
New York, New York 1,000,000

Cornell University
Ithaca, New York 2,000,000

Dartmouth College
Hanover, New Hampshire 1,000,000

Duke University
Durham, North Carolina 1,500,000

Emory University
Atlanta, Georgia 1,000,000

Indiana University at Bloomington
Bloomington, Indiana 2,000,000

Johns Hopkins University
Baltimore, Maryland 1,000,000

Lehigh University
Bethlehem, Pennsylvania 1,000,000

Louisiana State University and A&M University
Baton Rouge, Louisiana 1,000,000

Massachusetts Institute of Technology
Cambridge, Massachusetts 1,000,000

Miami University
Oxford, Ohio 1,000,000

New York University
New York, New York 1,200,000

Ohio State University
Columbus, Ohio 1,200,000

Pennsylvania State University Main Campus
University Park, Pennsylvania 1,200,000

Princeton University
Princeton, New Jersey 1,000,000

Purdue University Main Campus
West Lafayette, Indiana 1,000,000

Rensselaer Polytechnic Institute
Troy, New York 1,000,000

Rice University
Houston, Texas 1,000,000

Stanford University
Stanford, California 1,000,000

Stevens Institute of Technology
Hoboken, New Jersey 1,000,000

Tufts University
Medford, Massachusetts 1,500,000

University of Arizona
Tucson, Arizona 1,500,000

University of California–Davis
Davis, California 1,200,000

University of California–Irvine
Irvine, California 1,200,000

University of California–San Diego
San Diego, California 1,200,000

University of California–Santa Cruz
Santa Cruz, California 1,000,000

University of Chicago
Chicago, Illinois 2,000,000

University of Colorado
Colorado Springs, Colorado 2,000,000

University of Illinois at Chicago
Chicago, Illinois 1,000,000

University of Illinois at Urbana-Champaign
Urbana, Illinois 1,500,000

University of Kansas Main Campus
Lawrence, Kansas 1,000,000

University of Minnesota–Twin Cities
Minneapolis, Minnesota 1,000,000

University of Missouri–Columbia
Columbia, Missouri 1,000,000

University of North Carolina at Chapel Hill
Chapel Hill, North Carolina 1,500,000

University of Pennsylvania
Philadelphia, Pennsylvania 1,200,000

University of Puerto Rico Rio Piedras Campus
Rio Piedras, Puerto Rico 1,200,000

University of Southern California
Los Angeles, California 1,000,000

University of Texas at Austin
Austin, Texas 1,000,000

University of Utah
Salt Lake City, Utah 1,200,000

University of Vermont
Burlington, Vermont 1,000,000

University of Virginia
Charlottesville, Virginia 1,000,000

University of Washington
Seattle, Washington 1,000,000

University of Wisconsin–Madison
Madison, Wisconsin 1,200,000

Wayne State University
Detroit, Michigan 1,200,000

Yale University
New Haven, Connecticut 1,000,000

Total $61,000,000

Undergraduate Biological Sciences Education Program—1991 Awards

Antioch University Yellow Springs, Ohio	$600,000
Barnard College New York, New York	900,000
Bates College Lewiston, Maine	900,000
Beloit College Beloit, Wisconsin	650,000
California State University–Long Beach Long Beach, California	750,000
California State University–Los Angeles Los Angeles, California	800,000
Calvin College Grand Rapids, Michigan	500,000
Canisius College Buffalo, New York	700,000
Centre College Danville, Kentucky	500,000
City University of New York Brooklyn College Brooklyn, New York	1,200,000
City University of New York Queens College Flushing, New York	1,100,000
Colby College Waterville, Maine	1,000,000
Colgate University Hamilton, New York	900,000
College of the Holy Cross Worcester, Massachusetts	600,000
Cooper Union New York, New York	750,000
Eckerd College St. Petersburg, Florida	550,000
Fisk University Nashville, Tennessee	700,000
Fort Lewis College Durango, Colorado	800,000
Gettysburg College Gettysburg, Pennsylvania	850,000
Goucher College Towson, Maryland	500,000
Hamilton College Clinton, New York	700,000
Harvey Mudd College Claremont, California	500,000
Hiram College Hiram, Ohio	700,000
Hope College Holland, Michigan	750,000
Illinois Benedictine College Lisle, Illinois	500,000
Jackson State University Jackson, Mississippi	700,000
Juniata College Huntingdon, Pennsylvania	900,000
King College Bristol, Tennessee	500,000
Knox College Galesburg, Illinois	500,000
Lafayette College Easton, Pennsylvania	600,000
Lawrence University Appleton, Wisconsin	700,000
Manhattan College Riverdale, New York	500,000
Nebraska Wesleyan University Lincoln, Nebraska	500,000
Ohio Wesleyan University Delaware, Ohio	700,000
Reed College Portland, Oregon	1,000,000
San Diego State University San Diego, California	1,200,000
Spelman College Atlanta, Georgia	900,000
University of Puerto Rico Mayaguez Campus Mayaguez, Puerto Rico	500,000
University of Scranton Scranton, Pennsylvania	700,000
University of Texas at San Antonio San Antonio, Texas	650,000
University of the South Sewanee, Tennessee	500,000
Ursinus College Collegeville, Pennsylvania	500,000
Villanova University Villanova, Pennsylvania	650,000
Williams College Williamstown, Massachusetts	900,000
Total	**$31,500,000**

Undergraduate Biological Sciences Education Program—1992 Awards

Arizona State University, Tempe, Arizona	$1,500,000
Auburn University, Auburn University, Alabama	1,000,000
Boston University, Boston, Massachusetts	1,000,000
Brandeis University, Waltham, Massachusetts	1,400,000
California Institute of Technology, Pasadena, California	2,000,000
Georgetown University, Washington, D.C.	1,000,000
Harvard University, Cambridge, Massachusetts	1,100,000
Illinois Institute of Technology, Chicago, Illinois	1,000,000
Iowa State University, Ames, Iowa	1,300,000
Kansas State University, Manhattan, Kansas	1,200,000
Marquette University, Milwaukee, Wisconsin	1,200,000
Michigan State University, East Lansing, Michigan	1,200,000
North Carolina State University, Raleigh, North Carolina	1,000,000
Oklahoma State University, Stillwater, Oklahoma	2,000,000
Rutgers the State University of New Jersey, Newark Campus, Newark, New Jersey	1,200,000
State University of New York at Albany, Albany, New York	1,200,000
State University of New York at Binghamton, Binghamton, New York	1,500,000
Texas Tech University, Lubbock, Texas	1,300,000
University of California–Berkeley, Berkeley, California	2,000,000
University of California–Los Angeles, Los Angeles, California	1,300,000
University of California–Santa Barbara, Santa Barbara, California	1,000,000
University of Cincinnati, Cincinnati, Ohio	1,000,000
University of Delaware, Newark, Delaware	1,000,000
University of Georgia, Athens, Georgia	1,400,000
University of Hawaii at Manoa, Manoa, Hawaii	1,000,000
University of Iowa, Iowa City, Iowa	1,100,000
University of Kentucky, Lexington, Kentucky	1,000,000
University of Maryland College Park, College Park, Maryland	1,300,000
University of Massachusetts at Amherst, Amherst, Massachusetts	1,200,000
University of Michigan–Ann Arbor, Ann Arbor, Michigan	1,400,000
University of Nebraska–Lincoln, Lincoln, Nebraska	1,000,000
University of Nevada, Reno, Reno, Nevada	1,100,000
University of New Mexico, Albuquerque, New Mexico	1,000,000
University of Notre Dame, Notre Dame, Indiana	1,500,000
University of Oregon, Eugene, Oregon	1,000,000
University of Pittsburgh, Pittsburgh Campus, Pittsburgh, Pennsylvania	1,700,000
University of Rochester, Rochester, New York	1,000,000
University of South Carolina–Columbia, Columbia, South Carolina	1,000,000
Vanderbilt University, Nashville, Tennessee	1,200,000
Washington State University, Pullman, Washington	1,500,000
Washington University, Saint Louis, Missouri	1,700,000
West Virginia University, Morgantown, West Virginia	1,000,000
Total	**$52,500,000**

Undergraduate Biological Sciences Education Program—1993 Awards

Amherst College Amherst, Massachusetts	$500,000
Bates College Lewiston, Maine	500,000
Bowdoin College Brunswick, Maine	550,000
Bryn Mawr College Bryn Mawr, Pennsylvania	600,000
California State University–Los Angeles Los Angeles, California	650,000
California State University–Northridge Northridge, California	700,000
Carleton College Northfield, Minnesota	850,000
City University of New York City College New York, New York	650,000
City University of New York Herbert H. Lehman College Bronx, New York	500,000
City University of New York Hunter College New York, New York	650,000
Clark Atlanta University Atlanta, Georgia	550,000
College of the Holy Cross Worcester, Massachusetts	550,000
Colorado College Colorado Springs, Colorado	650,000
Concordia College–Moorhead Moorhead, Minnesota	550,000
Fisk University Nashville, Tennessee	550,000
Fort Lewis College Durango, Colorado	500,000
Gettysburg College Gettysburg, Pennsylvania	500,000
Hampton University Hampton, Virginia	500,000
Haverford College Haverford, Pennsylvania	600,000
Hobart and William Smith Colleges Geneva, New York	550,000
Humboldt State University Arcata, California	800,000
Knox College Galesburg, Illinois	500,000
Morehouse College Atlanta, Georgia	1,000,000
Oberlin College Oberlin, Ohio	500,000
Ohio Wesleyan University Delaware, Ohio	500,000
Saint Joseph's University Philadelphia, Pennsylvania	500,000
St. Mary's University San Antonio, Texas	650,000
Saint Olaf College Northfield, Minnesota	500,000
San Diego State University San Diego, California	500,000
Smith College Northampton, Massachusetts	600,000
Southern University and A&M College at Baton Rouge Baton Rouge, Louisiana	700,000
Swarthmore College Swarthmore, Pennsylvania	650,000
Tougaloo College Tougaloo, Mississippi	500,000
Tuskegee University Tuskegee, Alabama	500,000
Union College Schenectady, New York	500,000
University of Puerto Rico Cayey University College Cayey, Puerto Rico	600,000
University of Puerto Rico Mayaguez Campus Mayaguez, Puerto Rico	500,000
University of Puerto Rico Rio Piedras Campus Rio Piedras, Puerto Rico	500,000
University of Texas at El Paso	850,000
Ursinus College Collegeville, Pennsylvania	500,000
Wellesley College Wellesley, Massachusetts	850,000
Wesleyan University Middletown, Connecticut	500,000
Western Maryland College Westminster, Maryland	500,000
Wheaton College Wheaton, Illinois	550,000
Williams College Williamstown, Massachusetts	500,000
Wofford College Spartanburg, South Carolina	700,000
Xavier University of Louisiana New Orleans, Louisiana	1,400,000
Total	**$28,500,000**

Undergraduate Biological Sciences Education Program—1994 Awards

Arizona State University
Tempe, Arizona $1,000,000

Auburn University
Auburn University, Alabama 1,000,000

Boston University
Boston, Massachusetts 1,200,000

Brown University
Providence, Rhode Island 1,500,000

California Institute of Technology
Pasadena, California 1,200,000

Carnegie Mellon University
Pittsburgh, Pennsylvania 1,500,000

Case Western Reserve University
Cleveland, Ohio 2,000,000

Catholic University of America
Washington, D.C. 1,200,000

Cornell University
Ithaca, New York 2,000,000

Dartmouth College
Hanover, New Hampshire 1,800,000

Duke University
Durham, North Carolina 1,800,000

Emory University
Atlanta, Georgia 1,200,000

Georgia Institute of Technology
Atlanta, Georgia 1,000,000

Harvard University
Cambridge, Massachusetts 1,000,000

Howard University
Washington, D.C. 1,800,000

Johns Hopkins University
Baltimore, Maryland 1,800,000

Lehigh University
Bethlehem, Pennsylvania 1,500,000

Louisiana State University and A&M College
Baton Rouge, Louisiana 1,200,000

Massachusetts Institute of Technology
Cambridge, Massachusetts 1,600,000

Miami University
Oxford, Ohio 1,000,000

Mississippi College
Clinton, Mississippi 1,000,000

New York University
New York, New York 1,300,000

Oklahoma State University Main Campus
Stillwater, Oklahoma 1,000,000

Oregon State University
Corvallis, Oregon 2,000,000

Pennsylvania State University Main Campus
University Park, Pennsylvania 1,000,000

Princeton University
Princeton, New Jersey 1,300,000

Rice University
Houston, Texas 1,600,000

Rutgers the State University of New Jersey New Brunswick
Campus, New Brunswick, New Jersey 1,400,000

Stanford University
Stanford, California 1,800,000

State University of New York at Binghamton
Binghamton, New York 1,000,000

State University of New York at Buffalo
Buffalo, New York 1,500,000

State University of New York at Stony Brook
Stony Brook, New York 1,000,000

Temple University
Philadelphia, Pennsylvania 1,200,000

Texas A&M University
College Station, Texas 1,700,000

Texas Tech University
Lubbock, Texas 1,000,000

Tufts University
Medford, Massachusetts 1,800,000

University of Arizona
Tucson, Arizona 2,000,000

University of Arkansas Main Campus
Fayetteville, Arkansas 1,000,000

University of California–Davis
Davis, California 2,000,000

University of California–San Diego
La Jolla, California 1,100,000

University of Chicago
Chicago, Illinois 1,800,000

University of Colorado at Boulder
Boulder, Colorado 1,800,000

University of Georgia
Athens, Georgia 1,000,000

University of Illinois at Urbana-Champaign
Urbana, Illinois 1,200,000

University of Iowa
Iowa City, Iowa 1,000,000

University of Massachusetts at Amherst 1,000,000

University of Miami
Coral Gables, Florida 2,000,000

University of Missouri–Columbia
Columbia, Missouri 1,300,000

University of Nebraska–Lincoln
Lincoln, Nebraska 1,000,000

University of New Orleans
New Orleans, Louisiana 1,500,000

University of North Carolina at Chapel Hill 2,000,000

University of North Dakota Main Campus
Grand Forks, North Dakota 1,600,000

University of South Dakota
Vermillion, South Dakota 1,100,000

University of Tennessee
Knoxville, Tennessee 1,400,000

University of Texas at Austin 1,000,000

University of Washington
Seattle, Washington 1,800,000

University of Wisconsin–Madison
Madison, Wisconsin 1,000,000

Utah State University
Logan, Utah 1,400,000

Vanderbilt University
Nashville, Tennessee 1,000,000

Washington University
Saint Louis, Missouri 1,400,000

Wayne State University
Detroit, Michigan 1,100,000

Yale University
New Haven, Connecticut 1,600,000

Total $86,000,000

Undergraduate Biological Sciences Education Program Awardee Institutions by Carnegie Classification, 1989–1994*

The Carnegie Foundation for the Advancement of Teaching classifies colleges and universities on the basis of such factors as the range of the baccalaureate program, number of Ph.D. degrees awarded annually, and amount of annual federal support for research and development, as appropriate. The Institute's assessments of institutions for the 1989–1993 competitions were based on the 1987 Carnegie Foundation classifications and included the following classifications and categorical definitions for public and private institutions:

Research Universities I: These institutions offer a full range of baccalaureate programs, are committed to graduate education through the doctorate degree, and give high priority to research. They receive annually at least $33.5 million in federal support and award at least 50 Ph.D. degrees each year.

Research Universities II: These institutions offer a full range of baccalaureate programs, are committed to graduate education through the doctorate degree, and give high priority to research. They receive annually between $12.5 million and $33.5 million in federal support for research and development and award at least 50 Ph.D. degrees each year.

Doctorate-Granting Universities I: In addition to offering a full range of baccalaureate programs, the mission of these institutions includes a commitment to graduate education through the doctorate degree. They award at least 40 Ph.D. degrees annually in five or more academic disciplines.

Doctorate-Granting Universities II: In addition to offering a full range of baccalaureate programs, the mission of these institutions includes a commitment to graduate education through the doctorate degree. They award annually 20 or more Ph.D. degrees in at least one discipline or 10 or more Ph.D. degrees in three or more disciplines.

Comprehensive Universities and Colleges I: These institutions offer baccalaureate programs and, with few exceptions, graduate education through the master's degree. More than half of their baccalaureate degrees are awarded in two or more occupational or professional disciplines such as engineering or business administration. All of the institutions in this group enroll at least 2,500 students.

Comprehensive Universities and Colleges II: These institutions award more than half of their baccalaureate degrees in two or more occupational or professional disciplines, such as engineering or business administration, and many also offer graduate education through the master's degree. All of the colleges and universities in this group enroll between 1,500 and 2,500 students.

Liberal Arts Colleges I: These highly selective institutions are primarily undergraduate colleges that award more than half of their baccalaureate degrees in arts and science fields.

Liberal Arts Colleges II: These institutions are primarily undergraduate colleges that are less selective and award more than half of their degrees in liberal arts fields. This category also includes a group of colleges that award less than half of their degrees in liberal arts fields but, with fewer than 1,500 students, are too small to be considered comprehensive.

Schools of Engineering and Technology: The institutions in this category award at least a bachelor's degree in programs limited almost exclusively to technical fields of study.

*Further information may be found in *Classification of Institutions of Higher Education*, Carnegie Foundation for the Advancement of Teaching, Princeton, N.J., 1994

Research Universities I
Boston University
California Institute of Technology
Carnegie Mellon University
Case Western Reserve University
Colorado State University
Columbia University
Cornell University
Duke University
Georgia Institute of Technology
Harvard University
Howard University
Indiana University at Bloomington
Johns Hopkins University
Louisiana State University and A&M College
Massachusetts Institute of Technology
Michigan State University
New York University
North Carolina State University
Ohio State University Main Campus
Oregon State University
Pennsylvania State University Main Campus
Princeton University
Rutgers the State University of New Jersey New Brunswick Campus
Stanford University
State University of New York at Stony Brook
Texas A&M University
University of Arizona
University of California–Berkeley
University of California–Davis
University of California–Irvine
University of California–Los Angeles
University of California–San Diego
University of Chicago
University of Cincinnati Main Campus
University of Colorado at Boulder
University of Georgia
University of Hawaii at Manoa
University of Illinois at Chicago
University of Illinois at Urbana-Champaign
University of Iowa
University of Kentucky
University of Maryland College Park
University of Miami
University of Michigan–Ann Arbor
University of Minnesota–Twin Cities
University of Missouri–Columbia
University of New Mexico Main Campus
University of North Carolina at Chapel Hill
University of Pennsylvania
University of Pittsburgh Pittsburgh Campus
University of Rochester
University of Southern California
University of Tennessee, Knoxville
University of Texas at Austin
University of Utah
University of Virginia
University of Washington
University of Wisconsin–Madison
Vanderbilt University
Washington University
Yale University

Research Universities II
Arizona State University
Auburn University
Brandeis University
Brown University
Emory University
Georgetown University
Iowa State University
Kansas State University
Oklahoma State University Main Campus
Rensselaer Polytechnic Institute
State University of New York at Albany
State University of New York at Buffalo
Temple University
University of California–Santa Barbara
University of Delaware
University of Kansas Main Campus
University of Massachusetts at Amherst
University of Nebraska–Lincoln
University of Oregon
University of South Carolina–Columbia
Utah State University
Washington State University
Wayne State University
West Virginia University

Doctorate-Granting Universities I
Catholic University of America
College of William and Mary
Illinois Institute of Technology
Lehigh University
Marquette University
Miami University

Rice University
State University of New York at Binghamton
Texas Tech University
Tufts University
University of Arkansas Main Campus
University of California–Santa Cruz
University of Notre Dame
University of Puerto Rico Mayaguez Campus
University of Puerto Rico Rio Piedras Campus
University of Scranton
University of Texas at El Paso
University of Texas at San Antonio
Villanova University

Doctorate-Granting Universities II

Dartmouth College
Mississippi College
Rutgers the State University of New Jersey Newark Campus
Stevens Institute of Technology
University of Nevada, Reno
University of New Orleans
University of North Dakota Main Campus
University of South Dakota
University of Vermont

Comprehensive Universities and Colleges I

California State University–Long Beach
California State University–Los Angeles
California State University–Northridge
Calvin College
Canisius College
City University of New York Brooklyn College
City University of New York City College
City University of New York Herbert H. Lehman College
City University of New York Hunter College
City University of New York Queens College
Concordia College–Moorhead
Fort Lewis College
Hampton University
Humboldt State University
Jackson State University
Manhattan College
San Diego State University
Saint Joseph's University
St. Mary's University
Southern University and A&M College at Baton Rouge
Tuskegee University
University of Puerto Rico Cayey University College

Comprehensive Universities and Colleges II

Clark Atlanta University
Illinois Benedictine College
Xavier University of Louisiana

Liberal Arts Colleges I

Amherst College
Antioch University
Barnard College
Bates College
Beloit College
Bowdoin College
Bryn Mawr College
Carleton College
Centre College
Colby College
Colgate University
College of the Holy Cross
Colorado College
Eckerd College
Gettysburg College
Goucher College
Hamilton College
Haverford College
Hobart and William Smith Colleges
Hope College
Juniata College
King College
Knox College
Lafayette College
Lawrence University
Nebraska Wesleyan University
Oberlin College
Reed College
Saint Olaf College
Smith College
Swarthmore College
Union College
University of the South
Ursinus College
Wellesley College

Wesleyan University
Western Maryland College
Wheaton College
Williams College

Ohio Wesleyan University
Spelman College
Tougaloo College
Wofford College

Liberal Arts Colleges II
Fisk University
Hiram College
Morehouse College

Schools of Engineering and Technology
Cooper Union
Harvey Mudd College

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Undergraduate Biological Sciences Education Program Awardee Minority Institutions, 1989–1994

In the assessment of institutions for the 1991 and 1993 undergraduate grants competitions, the Institute has taken into account the institutions' records of graduating in the sciences students from minority groups underrepresented in scientific fields. Information for these assessments has been provided by the following sources:

The Minority Access to Research Careers Program of the National Institutes of Health. (This program was created in 1977 by the National Institute of General Medical Sciences to increase the number of biomedical scientists from minority groups.)

The Minority Biomedical Research Support Program of the National Institutes of Health. (This program was established in 1972 by the NIH Division of Research Resources to develop minority student, faculty, and institutional involvement in biomedical research.)

The National Association for Equal Opportunity in Higher Education. (This organization, founded in 1969, represents and serves some 117 historically and predominantly black colleges and universities.)

The Office of Civil Rights of the U.S. Department of Education. (This federal agency is responsible for analyzing and disseminating data on minority students at the nation's colleges and universities, including the number of degrees conferred, as submitted through the Integrated Post-Secondary Education System and required of all institutions.)

Historically Black Institutions

Clark Atlanta University
Fisk University
Hampton University
Howard University
Jackson State University
Morehouse College
Southern University and A&M College at Baton Rouge
Spelman College
Tougaloo College
Tuskegee University
Xavier University of Louisiana

Institutions with Significant Underrepresented Minority Student Presence in the Sciences

California State University–Long Beach
California State University–Los Angeles
City University of New York Brooklyn College
City University of New York City College
City University of New York Herbert H. Lehman College
City University of New York Hunter College
Fort Lewis College
St. Mary's University
University of Puerto Rico Cayey University College
University of Puerto Rico Mayaguez Campus
University of Puerto Rico Rio Piedras Campus
University of Texas at El Paso
University of Texas at San Antonio

Undergraduate Biological Sciences Education Program Awardee Institutions by State, 1989–1994

Alabama
Auburn University, Auburn University
Tuskegee University, Tuskegee

Arizona
Arizona State University, Tempe
University of Arizona, Tucson

Arkansas
University of Arkansas Main Campus, Fayetteville

California
California Institute of Technology, Pasadena
California State University–Long Beach
California State University–Los Angeles
California State University–Northridge
Humboldt State University, Arcata
Harvey Mudd College, Claremont
San Diego State University, San Diego
Stanford University, Stanford
University of California–Berkeley
University of California–Davis
University of California–Irvine
University of California–Los Angeles
University of California–San Diego, La Jolla
University of California–Santa Barbara
University of California–Santa Cruz
University of Southern California, Los Angeles

Colorado
Colorado College, Colorado Springs
Colorado State University, Fort Collins
Fort Lewis College, Durango
University of Colorado at Boulder

Connecticut
Wesleyan University, Middletown
Yale University, New Haven

Delaware
University of Delaware, Newark

District of Columbia
Catholic University of America, Washington, D.C.
Georgetown University, Washington, D.C.
Howard University, Washington, D.C.

Florida
Eckerd College, St. Petersburg
University of Miami, Coral Gables

Georgia
Clark Atlanta University, Atlanta
Emory University, Atlanta
Georgia Institute of Technology, Atlanta
Morehouse College, Atlanta
Spelman College, Atlanta
University of Georgia, Athens

Hawaii
University of Hawaii at Manoa, Honolulu

Illinois
Illinois Benedictine College, Lisle
Illinois Institute of Technology, Chicago
Knox College, Galesburg
University of Chicago, Chicago
University of Illinois at Urbana-Champaign, Urbana
Wheaton College, Wheaton

Indiana
Indiana University at Bloomington, Bloomington
Purdue University Main Campus, West Lafayette
University of Notre Dame, Notre Dame

Iowa
Iowa State University, Ames
University of Iowa, Iowa City

Kansas
Kansas State University, Manhattan
University of Kansas Main Campus, Lawrence

Kentucky
Centre College, Danville
University of Kentucky, Lexington

Louisiana
Louisiana State University and A&M College, Baton Rouge
Southern University and A&M College at Baton Rouge
University of New Orleans, New Orleans
Xavier University of Louisiana, New Orleans

Maine
Bates College, Lewiston
Bowdoin College, Brunswick
Colby College, Waterville

Maryland
Goucher College, Baltimore
Johns Hopkins University, Baltimore
University of Maryland, College Park
Western Maryland College, Westminster

Massachusetts
Amherst College, Amherst
Boston University, Boston
Brandeis University, Waltham
College of the Holy Cross, Worcester
Harvard University, Cambridge
Massachusetts Institute of Technology, Cambridge
Smith College, Northampton
Tufts University, Medford
University of Massachusetts at Amherst
Wellesley College, Wellesley
Williams College, Williamstown

Michigan
Calvin College, Grand Rapids
Hope College, Holland
Michigan State University, East Lansing
University of Michigan–Ann Arbor
Wayne State University, Detroit

Minnesota
Carleton College, Northfield
Concordia College–Moorhead
Saint Olaf College, Northfield
University of Minnesota–Twin Cities, St. Paul

Mississippi
Jackson State University, Jackson
Mississippi College, Clinton
Tougaloo College, Tougaloo

Missouri
University of Missouri–Columbia
Washington University, St. Louis

Nebraska
Nebraska Wesleyan University, Lincoln
University of Nebraska–Lincoln

Nevada
University of Nevada, Reno

New Hampshire
Dartmouth College, Hanover

New Jersey
Princeton University, Princeton
Rutgers the State University of New Jersey Newark Campus
Rutgers the State University of New Jersey New Brunswick Campus
Stevens Institute of Technology, Hoboken

New Mexico
University of New Mexico Main Campus, Albuquerque

New York
Barnard College, New York City
Canisius College, Buffalo
City University of New York Brooklyn College
City University of New York City College
City University of New York Herbert H. Lehman College
City University of New York Hunter College

City University of New York
Queens College
Colgate University, Hamilton
Columbia University, New York City
Cooper Union, New York City
Cornell University, Ithaca
Hamilton College, Clinton
Hobart and William Smith Colleges, Geneva
Manhattan College, Riverdale
New York University, New York City
Rensselaer Polytechnic Institute, Troy
State University of New York at Albany
State University of New York at Binghamton
State University of New York at Buffalo
State University of New York at Stony Brook
Union College, Schenectady
University of Rochester, Rochester

North Carolina
Duke University, Durham
North Carolina State University, Raleigh
University of North Carolina at Chapel Hill

North Dakota
University of North Dakota, Grand Forks

Ohio
Antioch University, Yellow Springs
Case Western Reserve University, Cleveland
Hiram College, Hiram
Miami University, Oxford
Oberlin College, Oberlin
Ohio State University Main Campus, Columbus
Ohio Wesleyan University, Delaware
University of Cincinnati Main Campus, Cincinnati

Oklahoma
Oklahoma State University Main Campus, Stillwater

Oregon
Oregon State University, Corvallis
Reed College, Portland
University of Oregon, Eugene

Pennsylvania
Bryn Mawr College, Bryn Mawr
Carnegie Mellon University, Pittsburgh
Gettysburg College, Gettysburg
Haverford College, Haverford
Juniata College, Huntington
Lafayette College, Easton
Lehigh University, Bethlehem
Pennsylvania State University Main Campus, University Park
Saint Joseph's University, Philadelphia
Swarthmore College, Swarthmore
Temple University, Philadelphia
University of Pennsylvania, Philadelphia
University of Pittsburgh Pittsburgh Campus
University of Scranton, Scranton
Ursinus College, Collegeville
Villanova University, Villanova

Rhode Island
Brown University, Providence

South Carolina
University of South Carolina–Columbia
Wofford College, Spartanburg

South Dakota
University of South Dakota, Vermillion

Tennessee
Fisk University, Nashville
King College, Bristol
University of the South, Sewanee
University of Tennessee, Knoxville
Vanderbilt University, Nashville

Texas
Rice University, Houston
St. Mary's University, San Antonio
Texas A&M University, College Station
Texas Tech University, Lubbock
University of Texas at Austin
University of Texas at El Paso
University of Texas at San Antonio

Utah
University of Utah, Salt Lake City
Utah State University, Logan

Vermont
University of Vermont, Burlington

Virginia
College of William and Mary, Williamsburg
Hampton University, Hampton
University of Virginia, Charlottesville

Washington
University of Washington, Seattle
Washington State University, Pullman

West Virginia
West Virginia University, Morgantown

Wisconsin
Beloit College, Beloit
Lawrence University, Appleton
Marquette University, Milwaukee
University of Wisconsin–Madison

Puerto Rico
University of Puerto Rico Cayey University College, Cayey
University of Puerto Rico Mayaguez Campus
University of Puerto Rico Rio Piedras Campus

General Publications

Grants for Science Education (annual)

Community Partnerships in Science Education, Washington, D.C., Metropolitan Area Precollege Science Education Initiatives (annual)

Fact Sheets on HHMI Grants Programs (program and technological orientations) (periodic)

Meetings of Grantees

Graduate Education Fellows Meetings

Meeting of Medical Student Fellows, Program and Abstracts (annual)

Meeting of Predoctoral and Physician Postdoctoral Fellows, Program and Abstracts (annual)

Undergraduate Program Directors Meetings

Attracting Students to Science: Undergraduate and Precollege Programs, 1992

Enriching the Undergraduate Laboratory Experience, 1993

Institutional Strategies for Enhancing Undergraduate Science Education, 1993

Science Education: Expanding the Role of Science Departments, 1994

New Tools for Science Education, 1995

Precollege Science Education Program

Precollege Program Directors Meetings

Science Museums: Creating Partnerships in Science Education, 1994

Science Museums: Enlisting Communities in Science Education Partnerships, 1995

Meeting the Challenges of Science Education Reform, 1996

Meeting of the Montgomery County Public Schools Student and Teacher Interns at the National Institutes of Health

Student and Teacher Internship Program (brochure) (annual)

Holiday Lectures on Science (brochure) (annual)

Da Vinci and Darwin in the Molecules of Life, Stephen K. Burley, M.D., D.Phil., and John Kuriyan, Ph.D., 1993

Genes, Gender, and Genetic Disorders, Shirley M. Tilghman, Ph.D., and Robert L. Nussbaum, M.D., 1994

The Double Life of RNA, Thomas R. Cech, Ph.D., 1995

International Program

Scientific Meeting of International Research Scholars from the Baltics, Central Europe, and the Former Soviet Union, Program, Abstracts, and Directory

Program Announcements

Graduate Science Education Program

Predoctoral Fellowships in Biological Sciences (annual)

Research Training Fellowships for Medical Students (annual)

Research Training Fellowships for Medical Students, Continued Award Application (annual)

Postdoctoral Research Fellowships for Physicians (annual)

Undergraduate Biological Sciences Education Program

Undergraduate Biological Sciences Education Program (biennial)

Precollege and Public Science Education Program

Precollege Science Education Program (biennial)

Research Resources for Medical Schools Program
Research Resources for Medical Schools Program
International Program
International Program (biennial)

Information Booklets
Graduate Science Education Program
Information for Medical Student Fellows and Fellowship Institutions (annual)
Information for Predoctoral Fellows and Fellowship Institutions (annual)
Information for Physician Postdoctoral Fellows and Fellowship Institutions (annual)
Undergraduate Biological Sciences Education Program
Information for Colleges and Universities Awarded Undergraduate Grants (annual)
Precollege and Public Science Education Program
Information for Science Museums and Biomedical Research Institutions Awarded Precollege Grants (biennial)
Research Resources for Medical Schools Program
Research Resources for Medical Schools Program (biennial)
International Program
Information for International Research Scholars and Grantee Institutions (biennial)

Program Directories
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Directory of Predoctoral Fellows
Directory of Medical Student Fellows
Directory of Physician Postdoctoral Fellows
Undergraduate Biological Sciences Education Program
Undergraduate Program Directory
Precollege Science Education Program
Precollege Science Education Program Directory
Research Resources for Medical Schools Program
Research Resources Program Directory
International Program
International Research Scholars Program Directory (See Meetings of Grantees, International Program)

Publications on the HHMI Grants Program may be requested from
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