Toward Institutional Transformation

Ideas and Recommendations from HHMI Professors and Undergraduate Program Directors

Joint Meeting of HHMI Professors *and* Undergraduate Program Directors

October 16–18, 2006

HHMI
HOWARD HUGHES MEDICAL INSTITUTE

Office of Grants and Special Programs

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On October 16–18, 2006, more than 100 HHMI professors and undergraduate program directors from colleges and universities met at the Institute to explore ways to institutionalize and sustain innovative approaches to undergraduate science education. The meeting consisted of a series of panel discussions and small-group breakout sessions that focused on four themes:

- Incorporating active-learning strategies and research courses into the undergraduate science curriculum
- Preparing postdoctoral and graduate students for their future roles as educators
- Fostering diversity in the sciences through research experiences and better mentoring
- Conducting outreach to precollege students and groups underrepresented in the sciences

Participants were also offered an opportunity to work together on proposals for a new series of minigrants that would further explore some of the ideas raised at the meeting.

Active-Learning and Research Courses

The first panel focused on strategies to incorporate active-learning techniques and research experiences into undergraduate science courses and to make these an integral, sustainable part of the curriculum.

INSTITUTIONALIZING PROBLEM-BASED LEARNING

Harold White III (professor, Department of Chemistry and Biochemistry, University of Delaware), reviewed the school's 14-year effort to improve undergraduates' understanding of science through problem-based learning (PBL). PBL is a form of active learning that helps prepare students to conduct independent research by engaging them in vigorous investigations of real-life situations. Working in small groups, students identify a problem and then find the information necessary to solve it. The instructor suggests options and resources, provides guidance, and encourages the groups to operate independently.

> *"Incorporating PBL in freshman courses can be a shock to students, but it changes their thinking for their entire academic careers—they become independent learners."*
>
> **—Harold White III, University of Delaware**

White reported that PBL has been adopted in about 85 percent of biochemistry courses at the university. This institutionalization of PBL was due to several key factors, he noted. First, the PBL program was initiated and developed by a "critical mass" of faculty who were interested in change.

A PERSPECTIVE ON SUSTAINING CHANGE IN SCIENCE EDUCATION

In his keynote address, Frank Rhodes, president emeritus of Cornell University and author of *The Creation of the Future: The Role of the American University,*[1] noted that for the United States to maintain its economic preeminence, it must produce more scientists and engineers as well as more citizens who understand and support the scientific venture. For colleges and universities, this mandate translates into a mission: the transformation of undergraduate science education. Educators must move away from rigid, didactic teaching styles and make science engaging and relevant to students' experiences. In short, Rhodes said, "we must make science an adventure that addresses the issues of our time." Today, he observed, scientific problems are presented without historical context and are stripped of their social and economic consequences. Rhodes urged the audience to help counteract this trend. He asked the meeting participants to consider linking the sciences and liberal arts to focus on sustaining human communities and the earth; this transformation would add relevance, coherence, and immediacy to the entire educational process. Rhodes believes that an interdisciplinary approach to teaching that incorporates the liberal arts is critical for developing good scientists. Ultimately, Rhodes concluded, we need to create teams of independent thinkers to "grapple with how to sustain this aged, benevolent, crowded, depleted, and beautiful planet."

Rhodes observed that HHMI continues to lead in making science education more relevant and exciting. Nonetheless, if science education is to be truly transformed, college and university faculty and administrators must become more strongly committed to a cohesive and sustainable approach to education. He observed that the transformation of science education should be gradual to better ensure buy-in across faculty and administrators, with faculty moving into administrative positions and each college or university free to pursue lines of inquiry that best mesh with its mission. Good teaching should be rewarded and made as important as solid research in faculty's career advancement. Further, innovations in science education should be institutionalized through permanent shifts in resource allocation among academic departments.

Rhodes also observed that since the 19th century, science educators have been debating how to effectively teach an ever-expanding body of knowledge. He suggested that educators focus instead on teaching critical-thinking skills. However, he acknowledged that this approach might not enable students to meet admission requirements for medical, engineering, or other professional schools and he observed that resolving this issue is one of the key challenges faced by science educators today. The response, he suggested, should include involving professional school faculty in the transformation process.

Second, an egalitarian structure was created for the PBL program to encourage diverse faculty to be involved. For example, equal pay was provided for participants, who included males and females drawn from the tenure- and nontenure-track faculty of the biology, biochemistry, chemistry, and physics departments.

A third factor was national recognition in the form of grant support and awards. White reported that the PBL program has received grants from

1. Rhodes, Frank H.T. *The Creation of the Future: The Role of the American University.* Ithaca, NY: Cornell University Press, 2001.

HHMI, the National Science Foundation, and other prominent funders. It has also received national awards such as the TIAA-CREF Institute's Hesburgh Award. This support and recognition increased PBL's credibility with the university administration, which nurtured the program by increasing funding available for educational innovations and constructing PBL classrooms.

Fourth, multipronged dissemination of information about PBL increased its visibility at the university and beyond. Dissemination of PBL by University of Delaware faculty has been accomplished through workshops for educators (http://www.udel.edu/inst/), a Web-based PBL clearinghouse (https://chico.nss.udel.edu/Pbl/), publications (*The Power of Problem-Based Learning: A Practical "How To" for Teaching Undergraduate Courses in Any Discipline,* by Barbara J. Duch, Susan E. Groh, and Deborah E. Allen[2]), and conference presentations.

WEB-BASED RESOURCES FOR INTERDISCIPLINARY GENOMICS COURSES

Laurie J. Heyer (assistant professor, Department of Mathematics, Davidson College) discussed the development of Web-based genomics and bioinformatics courses at Davidson. The cornerstone of this effort is the Genome Consortium for Active Teaching (GCAT), which was created through the combined efforts of students and faculty in the biology, mathematics, and computer science departments. The GCAT (http://www.bio.davidson.edu/projects/gcat/gcat.html) brings microarray technology into the classroom to familiarize students with critical concepts and tools in genomics and bioinformatics. GCAT has a centralized chip reader that provides raw data and analyzes results for students. It also offers instructional materials for teachers, including ideas for microarray projects that illustrate key concepts. The GCAT Web site contains a link to Magic Tool software (http://www.bio.davidson.edu/projects/magic/magic.html), which helps students understand the mathematical computations required for large database analyses. Heyer reported that the GCAT's centralized chip reader helps make microarray experiments affordable and that GCAT and its supporting Magic Tool software are open source and can be used on all computers.

Heyer has launched a series of workshops to train faculty to use the resources of GCAT, particularly the teachers of student groups underrepresented in the sciences. She anticipates that over time the site will be the focal point of a global network of teachers using functional genomics in the undergraduate curriculum.

MUST HAVES FOR INSTITUTIONAL TRANSFORMATION

- Institutionalizing innovations in science education requires
- Support from faculty
- Support from the administration
- Recognition through competitive grant funding and national awards
- Dissemination through articles, books, workshops, and national meetings

2. Duch, Barbara J., Susan E. Groh, and Deborah E. Allen. *The Power of Problem-Based Learning: A Practical "How To" for Teaching Undergraduate Courses in Any Discipline.* Sterling, VA: Stylus Publishing, 2001.

Heyer reported that the mathematics department initially was skeptical about the GCAT interdisciplinary, active-learning approach. However, the project's demonstrated success overcame departmental resistance, and GCAT was expanded to include advanced classes for junior and senior biology, mathematics, and computer science majors in genomics, proteomics, and systems biology (http://www.bio.davidson.edu/courses/genomics/genomics.html). A bioinformatics course has been added for math majors (http://gcat.davidson.edu/bioinformatics/bioinf.html).

GCAT members are working with Drew Endy at the Massachusetts Institute of Technology to conduct synthetic biology research, participating in the International Genetically Engineered Machines (iGEM) competition, and partnering with HHMI professor Sarah C.R. Elgin at Washington University in St. Louis to sequence genomes as part of student research projects.

GENERATING RESEARCH EXPERIENCES WITHIN THE BIOLOGY COURSEWORK

Sarah C.R. Elgin (professor, Department of Biology, Washington University in St. Louis) spoke about her efforts to integrate research into biology courses (http://www.nslc.wustl.edu/elgin/genomics/index.html). The Washington University program has several components: The Genome Sequencing Center (GSC) Video Tour, available online at http://www.nslc.wustl.edu/elgin/genomics/gsc.html, is a guided tour of the GSC and provides an up-close look at the equipment used in high-throughput sequencing. It also includes animations of the processes used to sequence genomic DNA. Another component of the program is a sequence of computer-lab courses that familiarize students with online genomics tools before they move on to research-based lab courses.

Students enrolled in Experiments with Eukaryotic Microbes learn how to investigate a biological question in a model organism by working in teams and employing modern molecular and cell biology techniques. Student teams conduct literature searches and mine bioinformatics data as part of their study of a selected uncharacterized biological pathway in the model organism. In another course, Research Explorations in Genomics, juniors and seniors work as a team through a large-scale sequencing project, beginning with a sample preparation at the GSC through sequence finishing and analysis.

Elgin noted that the program is structured to help students become active participants in the culture of science. In addition, students' results may contribute to a genomics database available to all scientists in the field. She observed that the possibility of adding original data motivates the students and provides the impetus for doing the work meticulously. Not only do they learn about genetics and genomics, they also gain experience conducting research in a real-world context. Elgin reported some assessment results that showed that in addition to students having a better understanding of the nature of genes and genome sequencing, students' research experiences improved their ability to think independently.

SOME BENEFITS OF ACTIVE LEARNING

- Undergraduate involvement and class attendance increase, in part due to peer pressure that encourages student preparation and performance
- The interdisciplinary approach exposes students to diverse perspectives
- Faculty can quickly assess student abilities and performance

They also were better able to manage data, analyze and interpret results, and write up and defend their conclusions.

Elgin observed that institutionalizing research courses requires considering the interdisciplinary nature of current biological research and the varied scientific, computer, and mathematical expertise required to teach the courses. Other issues include selecting appropriate formats and problems, scheduling large blocks of lab time, providing sufficient lab equipment, and creating class activities that generate letter grades. She noted that research courses have similar or lower costs, in terms of both dollars and personnel, than individual mentored lab experiences.

IMPLEMENTING ACTIVE-LEARNING AND RESEARCH COURSES

Following the panel presentations, meeting participants talked about the issues involved in implementing active-learning and research courses. One challenge is how to "scale up" active-learning techniques such as PBL for use in large introductory courses. Participants offered the following suggestions:

- Have more lab sections comprising fewer students.
- Select problems and resources, such as databases like the one provided by GCAT, that can be realistically used in large classes.
- Have students who have completed the course serve as peer instructors.
- Rethink the goals of introductory courses and tailor them to focus on active learning rather than memorizing large amounts of information.

Participants also discussed whether it is important that students' research is at the "cutting edge," contributing to the body of scientific knowledge. This can be accomplished by using a low-tech, inexpensive microarray database such as the GCAT. Students are excited by the idea that they may be adding original work to a database used by other scientists.

> ***"Students are more motivated when they are discoverers of knowledge, not just receptors of knowledge."***
>
> **—Sarah C.R. Elgin, Washington University in St. Louis**

REPORT FROM THE SMALL-GROUP DISCUSSION ON ACTIVE LEARNING

The small-group session generated a number of ideas for implementing and assessing active-learning and research courses:

- Develop workshops to train faculty about assessment and active-learning across disciplines and create freshman courses that include research components.
- Involve postdoctoral and graduate students with faculty in designing research experiences.
- Mine available Web-based databases to find inexpensive microarray and other resources for undergraduate research courses. Build a compendium of research problems, contacts, and materials applicable to undergraduate research courses. (It was suggested that HHMI create a list of recommended Web sites and other materials pertaining to active-learning and research courses.)
- Have courses follow a progression in sophistication. Focus on breadth rather than depth of content and incorporate labs with thematic ideas. Initiate courses with a small selected group of undergraduates, such as an honors section, or integrate the courses into a freshman summer bridge program.

ACTIVE-LEARNING RESOURCES

Books

Bransford, John D., Ann L. Brown, and Rodney R. Cocking, eds. *How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy Press, 1999.

Duch, Barbara J., Susan E. Groh, and Deborah E. Allen. *The Power of Problem-Based Learning: A Practical "How To" for Teaching Undergraduate Courses in Any Discipline.* Sterling, VA: Stylus Publishing, 2001.

Moore, John. *Science as a Way of Knowing.* Cambridge, MA: Harvard University Press, 1993.

Dethier, Vincent G. *To Know a Fly.* San Francisco, CA: Holden-Day, 1962.

Web sites

Biology Education Network, http://biosci.aaas.org/portal/.

University of Delaware's PBL, http://www.udel.edu/pbl/.

PBL Problem Clearinghouse, https://chico.nss.udel.edu/pbl/.

Case Studies in Science, http://ublib.buffalo.edu/libraries/projects/cases/case.html.

Links to University of Delaware PBL course descriptions, http://www.udel.edu/chem/white/teaching.html.

SAKAI software (open source), http://www.sakaiproject.org/.

Mazur Group (at Harvard University) science education resources, http://mazur-www.harvard.edu/education/educationmenu.php.

Immediate Feedback Assessment Technique (IFAT) for group quizzes, http://www.epsteineducation.com/ifat.php.

Science education journals

Life Science Education, http://www.lifescied.org/.

Biochemistry and Molecular Biology Education, http://www.bambed.org/.

Liberal arts college teaching consortia

Middle Atlantic Association of Liberal Arts Chemistry Teachers, http://maalact.washcoll.edu/.

Middle Atlantic Discovery Chemistry Project, http://madcp.fandm.edu/.

Intercollegiate Student Chemists Convention, http://academic.ursinus.edu/isc/.

- Create an assessment resources Web site. Make the case for institutionalizing active-learning and research courses by gathering institutional data regarding retention, pass rates, course selection, and performance in subsequent courses.

Training the Next Generation of Educators

This panel looked at programs that provide post-doctoral and graduate students with experiences to better prepare them for their future roles as teachers and mentors. Jo Handelsman (professor, Department of Plant Pathology, University of Wisconsin–Madison) began the panel by discussing the new National Academy of Sciences report *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering*[3] and noting that the nation's future depends on eliminating the gender and racial/ethnic biases and outmoded rules governing academic success.

WISCONSIN PROGRAM FOR SCIENTIFIC TEACHING

Handelsman discussed initiatives of the Wisconsin Program for Scientific Teaching, which includes the HHMI Teaching Fellows Program (http://scientificteaching.wisc.edu/), the HHMI–National Academies Summer Institute for Undergraduate Education in Biology (http://AcademiesSummerInstitute.org), and a departmental experiment in teaching transformation. She explained that the postdoctoral and graduate students in the HHMI Teaching Fellows Program develop instructional materials that they then use to teach biology. After completing a mentoring course, the fellows also mentor undergraduate researchers. She observed that the institutionalization of this program will occur when there is

- Significant demand to participate from graduate students and postdoctoral scholars
- Evidence that these individuals come to the campus because of the teaching opportunities
- Evidence of improvements in the undergraduate experience
- Support from professional societies
- Reports that mentors empathize with their advisers
- Ease of replication

The Summer Institute trains biology educators from research universities. Handelsman reported that the program has been conducted since 2003 and has received collaborative support from HHMI, the National Academies, and the University of Wisconsin. Every year, 20 teams from research

A MODEL FOR SUSTAINABLE CHANGE

To effect transformation in science education, Handelsman suggested using a behavioral model adapted from smoking cessation, which recognizes that sustainable change follows a predictable progression, with challenges and setbacks along the way. For academic institutions, the progression involves identifying a problem, developing a solution, collecting evidence about whether the solution works, making the solution easy to replicate, replicating the solution repeatedly, and constantly assessing the outcomes.

3. Committee on Maximizing the Potential of Women in Academic Science and Engineering, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering.* Washington, DC: The National Academies Press, 2006.

universities attend a 5-day institute and develop instructional materials on topics of their choice for use in their courses. They test the materials in their classrooms and report on their results at a winter institute update meeting. Handelsman believes that institutionalization of this program will depend on

- Evidence supporting the change of teaching methods and tools
- Evidence that these teaching methods and tools enhance student learning
- Participants becoming ambassadors for change on their campuses
- Evidence of change at the participants' schools
- Ease of implementation
- The continuing commitment of program advocates

The third component of the University of Wisconsin program is an experiment in departmental transformation. The curriculum for the introductory course in bacteriology is being redesigned by faculty, instructors, and graduate students. Baseline data on the current course is being collected and the new course will be taught during the fall 2007 semester.

TEACHER-SCHOLARS AND THE ORDER PROGRAM

David Lynn (professor, Department of Chemistry and Biology, Emory University) noted that training the next generation of educators is a process requiring ongoing input, institutional transformation, and sustained support. He thanked Patricia Marstellar (director, Emory College Center for Science Education) for catalyzing and institutionalizing the transformation of science education at Emory and provided examples of what the university has accomplished.

To build interest in graduate and postdoctoral science programs, Emory invited a group of graduate students and postdoctoral scholars to teach about their discoveries. The project proved successful—about ten candidates applied for each slot—and has evolved into ORDER (On Recent Discoveries by Emory Researchers). This freshman seminar includes ten modules structured into two unified research-focused courses. The teacher-scholars use interactive lessons to guide students through the discovery process, moving them from the research question through the experiment and controls to the actual discovery and an understanding of its importance. For the final class assignment, the teacher-scholars mentor the students as they write and defend their own research proposals. An adjunct of ORDER, the Interdisciplinary Science Program for Integrating Research into Education (INSPIRE), integrates the natural and social sciences and promotes research across the university community.

Program assessment results indicate that ORDER benefits students and teacher-scholars. Research is brought into the classroom, and students are empowered to pursue their own investigations. In addition, the participating freshmen

- Learn about research opportunities at a large university while at a starting point in their academic careers
- Develop near-peer relationships with the teacher-scholars

For teacher-scholars, ORDER removes barriers to their larger involvement in the university and empowers them as educators. It also helps them enrich their understanding of the larger context of their own investigations and integrate their research interests with those of their peers in other disciplines.

Assessment results also demonstrate that ORDER is effective in generating interest in research and teaching among participants and in building broader outreach efforts. For example, all but one student in a recent ORDER seminar completed an independent research project by the end of his or her second year of college. In addition, of the 15 initial teacher-scholars, 10 accepted academic positions, 4 obtained postdoctoral appointments, and 1 is now an industrial research scientist.

Lynn observed that the research concepts and data generated by the ORDER and INSPIRE programs have become the basis for modules used on public broadcasting radio and television shows and are being incorporated into the introductory chemistry class, where teacher-scholars will be the primary educators.

RESEARCH-TEACHING FELLOWS PROGRAM

Thomas Strekas (professor and chair, Department of Chemistry and Biochemistry, City University of New York [CUNY]–Queens College) reported on a Queens College program that will support four research-teaching postdoctoral fellows in neuroscience and bioinformatics. With guidance from faculty mentors, these HHMI-funded fellows will conduct research and develop and teach courses. They also will mentor selected students from high school, undergraduate, and graduate programs. To reinforce the importance of each component, this new program

- Includes regular meetings of the fellows and their faculty mentors to discuss research, mentoring, and teaching issues
- Requires the fellows to provide regular written reports on their involvement in the research, teaching, and mentoring aspects of the program

In addition, two of the lead faculty mentors serve on a committee that reviews and enhances postdoctoral programs across the CUNY system.

Strekas suggested that institutionalization could be further promoted through the creation of teaching-research postdoctoral positions in which the college pays for the teaching component and grant funding supports the research component. He cautioned, however, that most institutions provide incentives that encourage focusing on research rather than teaching, especially at the postdoctoral level. Strekas recommended that institutions provide both rewards and oversight to balance their distribution, and that faculty mentors be committed to encouraging teaching and mentoring, as well as research.

REPORT FROM THE SMALL-GROUP DISCUSSION ON TRAINING THE NEXT GENERATION OF EDUCATORS

The small-group participants examined strategies for institutionalizing the researcher-educator model in colleges and universities. As a first step, HHMI professors and undergraduate program directors could help change the academic culture by

- Convincing principal investigators that teacher-scholar training programs benefit the research enterprise and encouraging prominent scientists to advocate for training in teaching
- Encouraging administrators to use both the “bully pulpit” and institutional incentives to demonstrate their support for good teaching
- Requiring new faculty to have completed teacher training and to have teaching experience
- Developing effective tools to assess teaching skills and including teaching competence in tenure decisions
- Rewarding faculty for exceptional teaching

To promote this cultural shift, several practical immediate steps could be taken. Graduate students could take the dean out to lunch to talk about impact of training in teaching. In advertising postdoctoral teaching positions, schools could emphasize excellent research opportunities for the postdocs to make the positions more attractive. HHMI professors and program directors could contact Elias Zerhouni (director, National Institutes of Health) to advocate for including a teacher education requirement in training grants. Peter Bruns (vice president, Office of Grants and Special Programs, HHMI) suggested that HHMI could develop a competition for grants that focused on teacher training for graduate students.

Student Research and Mentoring for Diversity

A third panel focused on best practices for research programs and mentoring strategies that encourage diversity in the sciences.

PROMOTING DIVERSITY IN THE SCIENCES: ELEMENTS OF SUCCESSFUL PROGRAMS

Julie Graf (executive director, Hughes Initiative, University of Colorado at Boulder) opened the discussion with an overview of national data that illustrated the need for programs that promote diversity in the sciences. For example, less than 15 percent of students receiving bachelor's degrees in science, technology, engineering, and mathematics (STEM) are from groups underrepresented in the sciences. Slightly more than 30 percent of all public high school graduates are college-ready, but only 9 percent of African American and Hispanic students are similarly prepared. Graf noted that by 2050, minorities underrepresented in the sciences will make up about 42 percent of the U.S. population. If current trends continue, most of these individuals will not have the education required to pursue STEM careers or to understand the importance of these fields to social progress.

PRINT AND WEB RESOURCES FOR TRAINING THE NEXT GENERATION OF TEACHERS

Burroughs Wellcome Fund and Howard Hughes Medical Institute. *Making the Right Moves: A Practical Guide to Scientific Management for Postdocs and New Faculty,* 2nd ed. 2006.

Handelsman, Jo et al. *Entering Mentoring: A Seminar to Train a New Generation of Scientists.* Madison, WI: Board of Regents of the University of Wisconsin System, 2005.

Handelsman, Jo et al. *Scientific Teaching: A Guide to Transforming Undergraduate Biology Education.* Greenwood Village, CO: Roberts and Company Publishers, in press.

National Research Council. *Bio2010: Transforming Undergraduate Education for Future Research Biologists.* Washington, DC: National Academies Press, 2003.

Preparing Future Faculty, http://www.preparing-faculty.org/.

Problem-Based Learning at the University of Delaware, http://www.udel.edu/pbl/.

Reinvention Center at Stony Brook, http://www.sunysb.edu/Reinventioncenter/.

The Wisconsin Program for Scientific Teaching, http://scientificteaching.wisc.edu/resources.htm.

To confound this prediction, Graf said, students from underrepresented minority groups need to be more fully engaged in the sciences through interactive learning and should be encouraged to give back to their communities. Programs, such as those at the University of Colorado, that are attaining these goals share the following characteristics:

- Substantial funding support for students and program administration
- Dedicated program staff who know the students, faculty, and research labs
- Faculty committed to providing research opportunities and advisers to provide ongoing academic and research guidance
- Mentors trained in diversity issues
- Coordination with other local and national college-level diversity programs
- Training for students in laboratory and scientific-writing skills and opportunities for students to participate in journal clubs and to present their research at local and national meetings
- Programs that are vertically integrated to include undergraduates in lab teams with graduate students and postdoctoral researchers
- Research opportunities ranging from entry level to advanced

TRANSFORMING SCIENCE EDUCATION AT A HISTORICALLY BLACK COLLEGE

Johnella E. Butler (provost and vice president for academic affairs, Spelman College) talked about two HHMI-funded programs at Spelman, a historically black college that emphasizes science education and community service. These programs are interdisciplinary efforts that focus on collaboration and mentoring and encourage student research.

The HHMI Summer Science Program exposes high school students to careers in biology and gives them opportunities to participate in biology research projects. It is being expanded to offer a residential experience that acclimates students to the college living and learning community. The HHMI Research Fellows Program enables students to conduct higher-level lab research. It has inspired the sponsorship of student research projects by other funders and has helped expand research capabilities in chemistry and biology labs. Recently, the Fellows Program focus areas have been enlarged to include course revision and new course development. In addition, the program is increasingly supporting new hires and infrastructure development.

Since their inception in 1993, the programs have provided research experiences for 208 Spelman students at the college; Morehouse School of Medicine; the Centers for Disease Control and Prevention; and Brown, Duke, and Emory universities. The programs also have provided travel support for more than 40 students to attend scientific conferences. The majority of students participating in these programs matriculate to graduate and professional schools, and many have obtained faculty positions at some of the nation's top research universities.

However, the transformation of science learning has created challenges for faculty and administrators. They include

- Incorporating the sciences into the liberal arts curriculum and determining which requirements should be met in the students' first-year curricula
- Balancing teaching, research, and service in the STEM disciplines
- Supporting release time for faculty to conduct research that does not disrupt the curriculum and that enhances teaching and the student experience

- Setting realistic research goals that mesh with the school's ability to raise funds for lab expansion and ongoing equipment maintenance as well as for new faculty
- Encouraging students to explore other careers in the life sciences besides medicine

COMPREHENSIVE AND SUSTAINED MENTORING TO PROMOTE ACADEMIC ACHIEVEMENT

Isiah Warner (professor, Department of Chemistry, Louisiana State University) described Louisiana State's programs for supporting undergraduate research and diversity. He began by enumerating key evidence-based benefits of undergraduate research programs and of educational diversity. Findings of a 2004 study[4] indicate that, overall, the students define undergraduate research as a powerful discovery tool that affects their identity and sense of career direction. The students showed significant increases in their higher-order reference and communication skills, especially in explaining, presenting, discussing, and defending their work. A 2003 diversity study[5] concluded that student experiences with diversity can promote more active, complex thinking and prepare students for participating in a multicultural society.

Both undergraduate research and diversity are incorporated in Louisiana State's HHMI Professors Program and LA-STEM Research Scholars Program. These programs provide research opportunities, including a summer bridge program, for students from local high schools and undergraduates not performing up to potential early in their academic careers. Graduate students and faculty serve as mentors, and undergraduates who succeed in the program become mentors for their peers. Recently, the program has been expanded—new educational, research, and mentoring projects have been created to help Professors Program graduates improve their higher-order thinking in STEM and in liberal arts subjects. The expansion will help undergraduates appreciate both the arts and sciences and make more informed career decisions. Students now move between the original and advanced program components, depending on their GPAs. Motivation to participate consistently in the advanced program includes a full scholarship.

Warner reported that Louisiana State is preparing an article for publication that assesses the results of these programs. He noted that the programs lead the nation in producing African American Ph.D.-level scientists. Warner attributes the students' successes, at least in part, to their early exposure to research.

MORE THOUGHTS ON BRIDGE PROGRAMS

Following the panel presentations, meeting participants further explored the subject of bridge programs as a way to increase diversity in the sciences. There was agreement that bridge programs

- Help many minority students make the transition between high school and college
- Can be effective student retention tools
- Should combine active learning and lectures to prepare participants for actual college classes
- Should include research mentors for students; these individuals could be selected from among the graduate students
- Should be supplemented with faculty training in pedagogy

4. Seymour, Elaine et al. "Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study." *Science Education* 88: 493–534, 2004.
5. Gurin, Patricia Y. et al. "How Does Racial/Ethnic Diversity Promote Education?" *The Western Journal of Black Studies* 27 (1), 2003.

REPORT FROM THE SMALL-GROUP DISCUSSION ON STUDENT RESEARCH AND MENTORING FOR DIVERSITY

The small-group discussion focused on strategies for developing sustainable, mentored research programs that encourage student diversity.

Strategies for mentoring include

- Providing students with authentic research experiences early in their undergraduate careers that include teamwork and opportunities to showcase their research results
- Focusing on inspiring students, such as inviting students who are not obviously the best in the class to join the lab, holding joint lab meetings with other groups of undergraduates conducting research, and having students work on publishable projects when possible
- Obtaining faculty buy-in
- Creating a mentorship hierarchy, in which college juniors and seniors mentor freshmen and sophomores, and university graduate students mentor undergraduates

Best practices for increasing diversity in the sciences include the following:

- Make a concerted effort to recruit diverse faculty. Efforts to hire diverse faculty can fail when the administration simply makes a position available or charges the hiring committee to consider diversity. In addition, administrators should try to hire faculty who have been involved with diversity efforts.
- Expose all students and faculty to diversity issues, including definitions of "normal," "different," and "majority" and how these definitions play out in various learning settings. Be aware of all aspects of "diversity" and that the term incorporates differences in color, ethnicity, sexual orientation, socioeconomic status, country/region/locality of origin, and gender.
- Pay attention and respond to each student's educational and personal issues. Keep in mind that the characteristics of a good mentor for minority students are the same as the characteristics of a good mentor for all students. Include program components that feature extensive faculty and student involvement to support weaker students. Incorporate the "posse" model; evidence has demonstrated that bringing together a group of students with similar backgrounds for a summer bridge experience helps them build confidence and establish the support networks necessary for academic success. Include program activities that build trust and explore different learning styles and cultures.
- Establish programs that involve high school science teachers, but not high school students because of possible lab liability issues.

Outreach

The final panel focused on strategies for preparing precollege and community college students to excel in the sciences.

XAVIER'S "STAR" PROGRAMS

Diedre Labat (professor, Xavier University of Louisiana) outlined Xavier's goals and outreach efforts to precollege students. Xavier is a Catholic, historically black university with an ongoing commitment to science education. Because students who pass precollege algebra are best prepared to do well in science, Xavier developed MathStar. This summer program provides preparatory active learning for 11- and 12-year-old students scheduled to take algebra in the fall. Anecdotal evidence of the program's success led to the development of the summer BioStar program for high school students scheduled to take biology and ChemStar for those beginning chemistry.

All of the “Star” programs are part of the Summer Academy of Science, which also offers SOAR (Stress on Analytical Reasoning) for high school juniors and seniors. The program has had proven success in helping students improve their SAT scores: a pretest/posttest survey found an increase of 120 points. SOAR graduates are not obligated to attend Xavier, but they do come away from the program with the understanding that the “Xavier campus is a safe place to be academically smart.” Labat noted that the Summer Academy reawakens students’ interest in science and is a valuable recruiting tool for Xavier.

HELPING COMMUNITY COLLEGE STUDENTS BRIDGE THE GAP

Michael Gaines (associate provost and professor of biology, University of Miami) discussed sustaining a bridge (i.e., transfer) program between a private research university and a state-supported two-year college. The University of Miami (UM) has significant numbers of Hispanic and black students (28% and 11%, respectively). Its partner school, Miami Dade College (MDC), has almost 60,000 students (about four times as many as the university), 66 percent of whom are Hispanic. Another 22 percent are black and 10 percent are white. Slightly more than two-thirds of the Bridge Scholars selected from MDC are Hispanic and 30 percent are black.

The bridge program goals are to increase the following:

- Academic competitiveness of MDC students
- Transfer rate of MDC students to UM
- Progression rate of these transfer students toward bachelor’s degrees in the sciences
- Number of MDC students who enter Ph.D. programs in the biomedical sciences

To help reach these goals, the scholars participate in research-based courses and seminars. They also attend national and emerging-scholar workshops, and their families are invited to attend science-based events.

Participating faculty are committed to sustaining the program. To achieve this end, the bridge program incorporates critical elements for sustaining an outreach partnership:

- *Communication.* Monthly meetings are held at the UM faculty club with MDC campus coordinators and UM faculty.
- *Trust.* UM faculty maintain honest, reliable communications with MDC, demonstrating that their goal is to cooperate with, not exploit, MDC.
- *Joint activities.* UM provides a transition course in chemistry for high school students planning to attend MDC and “Family Science Sundays.” The Sunday activities help families understand the value of research, but Gaines noted that assessment results thus far do not appear to justify continuing this expensive effort.
- *Support from the bottom up.* UM provides faculty mentors who work with bridge scholars to conduct research in the university labs on the Coral Gables, marine, and medical campuses.
- *Support from the top down.* Scholarships are provided for bridge students, and first-year UM students and MDC students work in teams to conduct research at UM labs.
- *Incentives for joining.* UM provides stipends for MDC faculty and students as well as support for new facilities at the two-year college.

Other critical elements for sustaining an outreach partnership are evaluation and leadership. Evaluation results thus far indicate that

- Bridge scholars are more likely than nonbridge scholars at MDC to transfer to a four-year institution and receive a bachelor’s degree in science

- Among the 73 students who have completed the program, about 25 percent are pursuing a medical degree, 11 percent are on track to receive a Ph.D. in the sciences, and about 10 percent are enrolling in dental or advanced pharmacy programs

Gaines observed that middle school and community college are critical junctures at which science interventions, for both students and teachers, can be effective.

PROGRAM TO PROMOTE CAREERS IN SCIENCE AND ENGINEERING

Iona Black (lecturer, Department of Chemistry, Yale University) described Yale's current and planned outreach activities. The STARS (Science, Technology and Research Scholars) initiative is a summer program for local high school students and for undergraduates from colleges and universities across the nation. The students attend classes together and develop research projects with Yale's science faculty. At the end of the program, students write research papers explaining their findings and make formal presentations at a research symposium. A recent assessment found that past program graduates were in advanced programs and that many had received Ph.D.s in the sciences.

Yale's latest outreach effort, Chemistry in the Popular Novel, is a one-semester course bringing together students from the sciences and liberal arts to create original short stories that employ science, especially chemistry. A course assessment found that all of the students had expanded their academic interests and their understanding of science: some have declared double majors, and the liberal arts majors are incorporating science in their senior theses.

Based on the results of these programs, Yale is moving ahead with workshops, targeted to Native American students from the Connecticut Nations community, that focus on Native American practices in science, especially chemistry.

REPORT FROM THE SMALL-GROUP DISCUSSION ON OUTREACH

The small-group discussion touched on issues related to program design, participant recruitment, and evaluation.

Program design. Cookie-cutter programs do not work; programs need to reflect community demographics and the needs of educators. (The group could not reach a consensus about whether content or pedagogical approaches were more important in conveying science to students.) It was suggested that science educators be hired to create and provide outreach programs. Programs that focused on both content and pedagogical approaches were thought to be successful in attracting and training teachers. One participant recommended the book *Designing Professional Development for Teachers of Science and Mathematics.*[6] Outreach programs for elementary grades might most effectively target teachers and those developed for middle and high school might best target both students and teachers. Both in-service and preservice training are important for teachers, and middle school teachers need special attention because they generally are less well prepared in the sciences. Some of the group members felt that teachers would be better served if science specialists were hired by the schools to guide teachers.

Participant recruitment. Teachers and students need incentives to participate; the best instructors for high school outreach programs might be

6. Loucks-Horsley, Susan et al. *Designing Professional Development for Teachers of Science and Mathematics,* 2nd ed. Thousand Oaks, CA: Corwin Press, 2003.

trained, skillful teachers; teachers need to feel valued in student outreach programs; student selection processes should target their teachers, not the school administrators. Graduate students are a potential source for providing outreach.

Evaluation. The process is difficult but necessary; success needs to be defined and clear, and measurable objectives must be identified; teachers and students should be tracked; evaluators should be experienced and independent of the program; evaluation results should be used to improve the program.

Reports on Minigrants

At the 2004 joint meeting of HHMI professors and undergraduate program directors, participants were invited to submit proposals to launch collaborative projects for transforming undergraduate science education. Two of the awardees reported on their projects during this session.

DIVERSITY SYMPOSIA

Wendy Raymond (associate professor, Department of Biology, Williams College) described the project Seeding Commitments to Diversity: Disseminating Effective Mentoring and Retention Programs, which is teaching others effective strategies for mentoring students from groups underrepresented in the sciences. Three symposia, hosted by Harvard University, the University of Louisiana at Monroe, and the University of Washington, are being led by faculty and administrators who have developed successful mentoring programs at University of Maryland–Baltimore County, University of California–Berkeley, Louisiana State University, and Xavier University of Louisiana. Raymond reported that more than 18 individuals at HHMI-supported institutions are collaborating on the project and that additional funding for the symposia has been provided by the host universities and the National Institutes of Health. (More information on the diversity symposia can be found at http://www.williams.edu/biuology/divsciences/ and http://www.hhmi.org/resources/diversity/.)

Raymond reported that teams from 76 colleges and universities around the country have attended or will attend one of the three symposia. There are strict requirements for the institutional teams attending a symposium: The teams must include a high-level administrator (e.g., president, dean), a science faculty member, and a student. Before the symposium, teams must submit data on the enrollment and grades of undergraduate life sciences students at their institutions, by race, gender, income level, and first-generation college status. Teams also must read recommended articles and create an action plan for increasing diversity among undergraduate life sciences students. Raymond reviewed the data submitted by institutions attending the November 2005 symposium and observed that enrollment of underrepresented minority students in biology courses steadily declines after the first freshman course and that many students decide whether to continue studying biology as early as the midterm exam in Biology 101. She also noted that African American and Hispanic biology majors do not achieve the same level of excellence as their Asian and white peers.

She advocated the following strategies to help address this problem:

- Offer a prefreshman summer program
- Pay attention to social aspects of thriving in college
- Use resources such as peer mentor programs
- Encourage students to participate in study groups
- Provide research experiences beginning the summer following the freshman year

She also commented on the key role that faculty can play, noting that "a single sentence of encouragement can change a student's life."

STUDENT RESPONSES TO RESEARCH EXPERIENCES

David Lopatto (professor, Department of Psychology, Grinnell College) presented updates on a series of online student survey projects funded with minigrants from HHMI, which collect data on the benefits of undergraduate research experiences. The first project, the Survey of Undergraduate Research Experiences (SURE), queries undergraduates who have recently completed a summer research experience. (A sample of the SURE survey can be found at http://web.grinnell.edu/sureii/sureii-summer-survey.pdf.) A second survey, SURE AY (academic year), targets undergraduates who have recently completed an academic year research experience. Students who indicate they have conducted research in the summer and during the academic year are provided with a set of questions that permit them to compare the two experiences. (A sample of the SURE AY survey can be found at http://web.grinnell.edu/sureiiay/sureii-academic-year-survey.pdf.) Lopatto noted that in 2005 the SURE surveys were retooled to include questions directed to undergraduates who had acted as peer mentors for other undergraduate researchers.

Data from the SURE summer and academic year surveys show that students who have participated in summer and academic year research experiences reported a variety of learning gains (e.g., readiness for more demanding research, learning to work independently, ability to analyze data).

A third survey, The Classroom Undergraduate Research Experiences (CURE) survey, can be used as a pretest/posttest or posttest only to assess student experiences in "research-like" or other science courses. Lopatto reported that the questions permit comparisons to the SURE data. Pretest questions collect demographic information, reasons for taking the course, level of experience on various course elements, attitudes about science, and learning styles. Posttest questions are similar to those in the pretest survey and also include questions about learning gains and attitudes about science. A "faculty course elements form" provides information on the activities emphasized in the course, permitting a classification of courses

TIPS FOR BETTER MENTORING TO INCREASE DIVERSITY IN THE SCIENCES

Faculty need to be proactive and sensitive to students' needs and insecurities:

- After the first midterm, identify students who are performing poorly and talk to them.
- In large classes, make it a point to talk to every student of color.
- Come into class a few minutes early, take a seat among the students, and start a casual conversation, perhaps by asking them if they can see the slides. Students then might feel more comfortable about stopping by the professor's office for academic help.
- Open up a tutoring center the first week of class for good students as well as struggling students. Encourage the good students to attend by offering practice tests. To reduce poorer students' feelings of being stigmatized, use the word "coaching" instead of "tutoring."
- Make sure that the good students who attend study groups do not "swamp" the poorer students. It was suggested that facilitated study groups might help address this potential problem and that coaches should be from groups underrepresented in the sciences.

that are more or less “research-like.” (Links to sample CURE survey questions can be found at http://www.grinnell.edu/academic/psychology/faculty/dl/sure&cure/.)

A comparison of the data with respect to funding source revealed higher mean responses among students funded by HHMI than by other sources. The difference was particularly striking in comparing the mean scores for learning lab techniques and ethical conduct, and for improving science writing skills and self-identified potential to become science teachers. For both groups, students reported the most gains in readiness for more research and for overall understanding of the research process. Lopatto also plotted the results from university-based programs against the results from college-based programs. The greatest gains for students in both groups were in understanding the research process and learning lab techniques. Both groups reported fewer gains in clarifying career goals, improving science-writing skills, and understanding ethical conduct. The survey also measured participant agreement with various concerns regarding the delivery of the research programs.

Lopatto compared SURE data to similar data on the CURE survey, which were gathered across 50 courses delivered in six schools. SURE data showed more learning gains than the CURE data. The highest SURE scores were reported for understanding the research process and how scientists work on problems, learning lab techniques, and becoming part of a learning community. The mean scores for “clarifying a career path” and “skills in oral presentations” were the lowest for both SURE and CURE among the parameters that could be compared. “Confidence in my potential to be a science teacher” was only measured by SURE and had the lowest mean score on the entire survey.

He added that information specific to each institution that participated in the surveys is confidential and shared only with that institution. However, parameters might be shifted in the future so that the highest-achieving programs are identified and their faculty made available to provide peer training.

Lopatto noted that the science community needs its own assessment tools. A robust set of standard items is being developed that can be used by institutions and correlated with their own specific data sets.

MORE ON THE SURE FINDINGS CAN BE FOUND IN THE FOLLOWING ARTICLES:

Lopatto, David. “Survey of Undergraduate Research Experiences (SURE): First Findings.” *Cell Biology Education,* 3:270–277, 2004, http://www.cellbioed.org/.

Lopatto, David. “What Undergraduate Research Can Tell Us About Research on Learning.” Washington, DC: Project Kaleidoscope, 2004, http://www.pkal.org/.