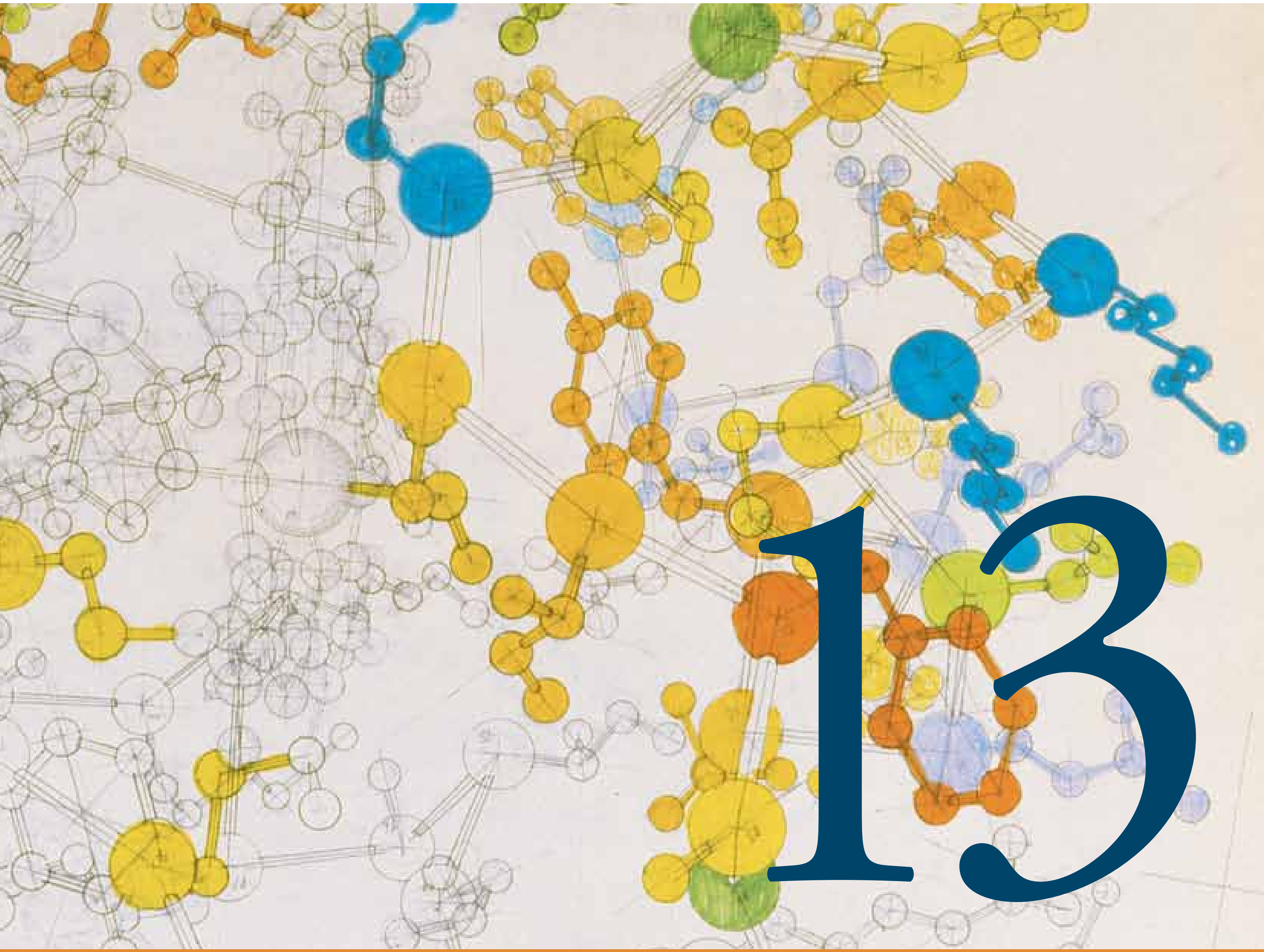


13

New Awards for Science Education to HHMI Professors

2010 Competition

HHMI
HOWARD HUGHES MEDICAL INSTITUTE

New Awards for Science Education to HHMI Professors

2010 Competition

On May 20, 2010, HHMI announced new grants for science education to research universities and professors. This booklet focuses on the awards to HHMI professors.

> "HHMI is committed to funding education programs that excite students' interest in science. We hope that these programs will shape the way students look at the world—whether those students ultimately choose to pursue a career in science or not."
>
> ROBERT TJIAN, PH.D. – PRESIDENT, HOWARD HUGHES MEDICAL INSTITUTE

The HHMI Professors Program

The HHMI Professors Program, created in 2002, helps top research scientists put their innovative ideas for science education into practice. The professors use their own research as the inspiration for classroom and training activities that convey the excitement of scientific research. The program's science education grants to individual researchers complement HHMI's grants to colleges and universities and reflect the Institute's support for the research community's participation in science education. The goal is to develop a group of educators at research universities around the country who are leaders in research *and* who excel in teaching.

HHMI professors have used their grants to develop a variety of projects. Several have transformed their own scientific interests into research projects that can be used in the classroom. Others have focused on improving student mentoring in hopes of increasing the number of students from diverse backgrounds who stay in science. Several more have worked to improve undergraduate teaching, especially in large introductory classes. Most of the grants have focused on undergraduates but some professors have included graduate students and postdocs or K–12 teachers and students in their activities, spreading the benefits of their programs to wider constituencies. The professors have used their awards to develop laboratory space and obtain new research equipment and other resources to support their science education activities. A number of professors have leveraged HHMI support to obtain additional funding from their home institutions.

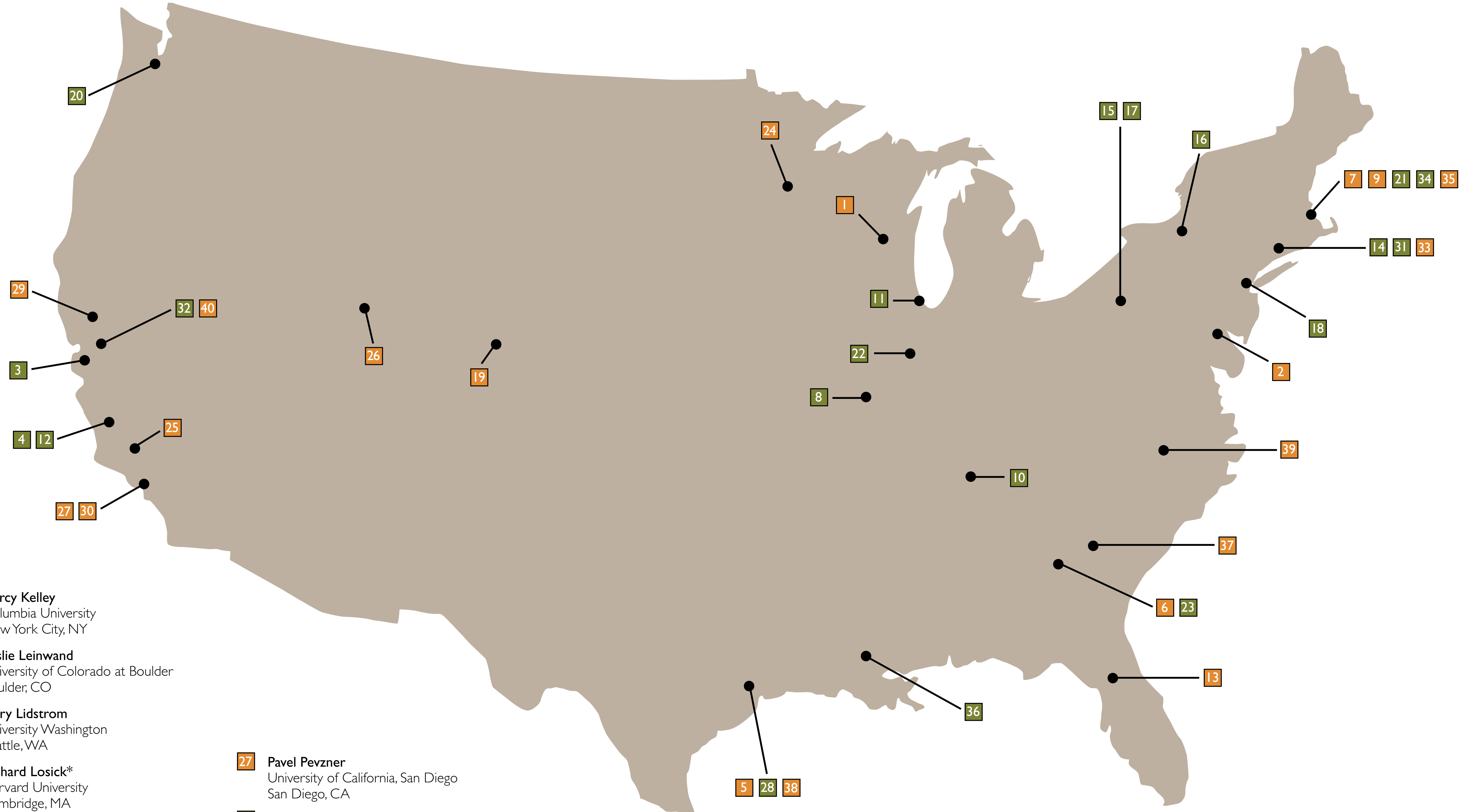
Appointment to the HHMI Professors Program is highly competitive. In 2002, the first cohort of professors was selected from a pool of 149 top scientists nominated by 79 institutions. Applications underwent rigorous review by scientists and educators, and 20 individuals were selected to receive $1 million each over four years. In 2006, a second cohort of 20 professors was selected from a pool of 150 nominated by 87 institutions. In addition, the 2002 professors were invited to submit renewal proposals, resulting in the extension of eight projects.

All HHMI professors had the opportunity to apply for reappointment in 2010. A panel of leading scientists and educators reviewed applications for activities with potential for significant impact beyond the professor's home institution. Thirteen professors, showcased here, were selected to expand on their original efforts. Projects include training scientists to teach based on the science of how people learn, extending research-based science curricula to new courses and universities, and sharing successful models for mentoring students in the sciences. The reappointed professors are poised to capitalize on what they have already developed and build the program into a national resource for science education.

To date, the Institute has awarded $44.9 million to support the science education activities of 40 professors at research universities across the United States.

To learn more about the HHMI professors and their education projects, visit **www.hhmi.org/grants/professors**.

The HHMI Professors



1 **Richard Amasino**
University of Wisconsin–Madison
Madison, WI

2 **Winston Anderson***
Howard University
Washington, D.C.

3 **Manuel Ares Jr.**
University of California, Santa Cruz
Santa Cruz, CA

4 **Utpal Banerjee***
University of California, Los Angeles
Los Angeles, CA

5 **Bonnie Bartel**
Rice University
Houston, TX

6 **Victor Corces**
Emory University
Atlanta, GA

7 **Catherine Drennan***
Massachusetts Institute of Technology
Cambridge, MA

8 **Sarah Elgin***
Washington University in St. Louis
St. Louis, MO

9 **Irving Epstein***
Brandeis University
Waltham, MA

10 **Ellen Fanning**
Vanderbilt University
Nashville, TN

11 **Hilary Godwin**
Northwestern University
Evanston, IL

12 **Robert Goldberg**
University of California, Los Angeles
Los Angeles, CA

13 **Louis Guillette Jr.**
University of Florida
Gainesville, FL

14 **Jo Handelsman***
Yale University
New Haven, CT

15 **Graham Hatfull***
University of Pittsburgh
Pittsburgh, PA

16 **Ron Hoy**
Cornell University
Ithaca, NY

17 **Elizabeth Jones** (deceased)
Carnegie Mellon University
Pittsburgh, PA

18 **Darcy Kelley**
Columbia University
New York City, NY

19 **Leslie Leinwand**
University of Colorado at Boulder
Boulder, CO

20 **Mary Lidstrom**
University Washington
Seattle, WA

21 **Richard Losick***
Harvard University
Cambridge, MA

22 **Yi Lu**
University of Illinois at Urbana-Champaign
Champaign, IL

23 **David Lynn**
Emory University
Atlanta, GA

24 **Claudia Neuhauser**
University of Minnesota, Rochester
Rochester, MN

25 **Diane O'Dowd***
University of California, Irvine
Irvine, CA

26 **Baldomero Olivera***
University of Utah
Salt Lake City, UT

27 **Pavel Pevzner**
University of California, San Diego
San Diego, CA

28 **Rebecca Richards-Kortum**
Rice University
Houston, TX

29 **Jasper Rine**
University of California, Berkeley
Berkeley, CA

30 **Robert Sah**
University of California, San Diego
San Diego, CA

31 **Alanna Schepartz**
Yale University
New Haven, CT

32 **Tim Stearns**
Stanford University
Palo Alto, CA

33 **Scott Strobel***
Yale University
New Haven, CT

34 **Graham Walker***
Massachusetts Institute of Technology
Cambridge, MA

35 **David Walt**
Tufts University
Medford, MA

36 **Isiah Warner***
Louisiana State University
Baton Rouge, LA

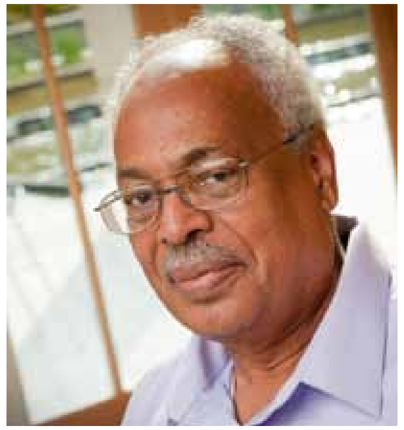
37 **Susan Wessler**
University of Georgia
Athens, GA

38 **Jennifer West**
Rice University
Houston, TX

39 **Hunt Willard**
Duke University
Durham, NC

40 **Richard Zare**
Stanford University
Palo Alto, CA

2002 COHORT
2006 COHORT
**Indicates reappointment in 2010*



WINSTON A. ANDERSON, PH.D.

Howard University
Washington, D.C.

Winston Anderson's research interests have ranged from trypanosomes to the mitochondria of sea urchin gametes to the role of estrogen and growth factors in cancer. A scientist who understands the importance of exposing students to contemporary research, Anderson has leveraged his award to provide opportunities for Howard undergraduates to conduct research at top universities. His Howard Hughes Medical Research Scholars program selects talented science and math majors for a research-intensive, mentored curriculum designed to give them a competitive edge for pursuing Ph.D. degrees in science. New initiatives will upgrade the science and mathematics curricula at Howard to prepare students for scientific careers.

If it sounds a little like an academic version of the Marine Corps, that's not far off. Give Winston Anderson a few good science undergraduates, he says, and in five years Howard University will have turned out 100 research-bound biomedical graduates with skills honed through intensive laboratory training in cutting-edge disciplines.

Anderson's goal is to give science students studying at Howard a "competitive edge" in entering biomedical research fields. At present, he adds, despite excellent teaching faculties and a large number of science majors at most HBCUs (Historically Black Colleges and Universities), "students cannot be adequately trained at our institutions because of lack of resources."

To address these shortcomings, Anderson has framed an ambitious HHMI professor proposal. Each year, he will handpick 20 juniors and seniors from a pool of honors science undergraduates. They'll be mentored by active researchers; do summer stints at universities and research centers such as the Marine Biological Laboratory in Woods Hole, Massachusetts, and Cold Spring Harbor Laboratory on Long Island, New York; and publish papers in peer-reviewed journals. Some will participate in summer exchange programs to African countries to study infectious and tropical diseases, principally in Mali, which has a thriving malaria and HIV/AIDS research center.

"If you provide these core units, identify the students early, and get them trained the right way, then they can be competitive, and that's what this program is about," Anderson says. While the research community in general remains concerned about flagging interest in science among high school and college students, "we don't have a problem at Howard," he notes. "We have 700 science majors," 1 in 10 of the 7,000 undergraduates at the urban university.

To make sure the academic pipeline to graduate and medical school stays filled, Anderson also plans to see that introductory courses in cell, developmental, and molecular biology and microbiology are upgraded to prepare honors sophomores for entry into the junior/senior honors research program. To provide the infrastructure to support these improvements, he will lead Howard in establishing core research laboratories with state-of-the-art facilities and equipment in computational mathematics, biophysics, genomics, proteomics, basic cell biology, and molecular biology.

Born in Jamaica, Anderson has combined a highly productive research career with a long track record of working to improve science education opportunities for minority students. As principal investigator of the National Science Foundation's Research Careers for Minority Scholars program, Anderson exposed 200 science and math students to contemporary research methods and facilities. He also heads the Fogarty International Center's Minority International Research Program, supporting the global training of minorities in the biomedical sciences.

UTPAL BANERJEE, PH.D.

University of California, Los Angeles
Los Angeles, CA

Utpal Banerjee's lab studies the patterns of gene expression that give rise to the development of organisms, focusing on nervous system and hematopoietic development in the fruit fly *Drosophila*. As HHMI professor, he has extended his scientific interests to provide course-based research opportunities to large numbers of early-stage undergraduates and high school students through UCLA's Undergraduate Research Consortium in Functional Genomics (URCFG). URCFG students use *Drosophila* as a model system in genome-wide functional analysis and expression-based lineage marking projects. In a newer initiative, students "deconstruct" research presentations in a guided process that helps them learn about the concepts and techniques of experimental science.

As a college student in India, Utpal Banerjee spent his summers working in research laboratories, and those experiences were pivotal in his decision to become a scientist. Ever since he became a professor himself, Banerjee has been trying to provide the next generation of undergraduate students the same kind of hands-on, inquiry-based education that he received. "Undergraduates can achieve a lot when shown the right way to think about problems," he says.

Banerjee's commitment to mentoring undergraduates started early. The first research to emerge from his newly formed molecular biology lab at the University of California, Los Angeles (UCLA), in 1991 was led by an undergraduate. As his lab grew, Banerjee added more undergrads and strengthened their initial training. "But all this was limited to my lab," he remembers. He thought there must be a way to reach more students.

With funding from the HHMI Professors Program in 2002, Banerjee scaled up his efforts, and UCLA's Undergraduate Research Consortium for Functional Genomics (URCFG) was born. A 10-week course enabled up to 30 undergraduates per academic quarter not only to learn their way around Banerjee's expanding laboratory but also to do real science. A few of those students were then offered the opportunity to do more advanced research over several years.

Using the fruit fly *Drosophila* as a model, Banerjee's molecular biology lab studies the patterns of gene expression that give rise to the development of organisms. The fruit fly is relatively easy to work with, and this kind of genomics needs hands-on attention—two factors that make the research well suited to a large team of basic trainees. In the first four years of the URCFG, more than 250 first- and second-year undergraduates helped produce two major papers—and an online database—detailing the effects of myriad gene deletions on the *Drosophila* eye.

Since then, Banerjee's teams of young scientists have moved from cataloging gene-deletion effects in *Drosophila* to recording gene-expression changes in various cell types as fruit flies develop—a project that yielded another massive database as well as a major paper in *Nature Methods*. Banerjee has put the latest groups to work on a new genomics project aimed at detailing the development of fruit fly blood cells.

So far, more than 500 students have been trained under the URCFG, and the program has expanded beyond Banerjee's lab to become an official biomedical research minor, which should make it possible for more students and UCLA faculty to participate. The URCFG also includes a new summer program for high school students.

Despite the program's success, Banerjee wants to reach even more students. He hopes to do that through a new course called Biomedical Research: Concepts and Strategies, which teaches students how scientific knowledge is gradually built from experimental evidence. Undergrads in this program listen to a scientific presentation and then, over eight weeks, learn to dissect and actively analyze the information they were given, through a guided process Banerjee calls "research deconstruction." "The idea is to impart the inquiry-based, critical thinking skills needed for research," he says. Over the past two years, more than 500 students have taken the course. Banerjee plans to expand it at UCLA, and he hopes to persuade other academic institutions to adopt it too.

To Banerjee, the research deconstruction idea is an inexpensive, scalable way to expose students to the culture of science and thereby nudge many of them toward a research career. But it can also be a valuable tool for educating all undergraduates. "Even if these students ultimately choose not to become scientists, learning to think like a scientist should help them in whatever profession they choose," he says. "Arguably, our society would be better off if more people had this as part of their education."

CATHERINE L. DRENNAN, PH.D.

Massachusetts Institute of Technology

Cambridge, MA

Catherine Drennan's lab uses crystallography as the chief tool for studying enzymes that are medically important or valuable in environmental remediation. Drennan was named an HHMI investigator in 2008 for her research on the structure and function of this special class of metalloproteins. Mirroring her own interdisciplinary interests, she has used her HHMI professor award to create resources to help students see the connections between biology and chemistry. As a committed scientist-educator, she is developing strategies to recruit tomorrow's top scientists from a diverse pool of freshman undergraduates and equip graduate student teaching assistants to be future teacher-scholars.

Catherine Drennan understands why some Massachusetts Institute of Technology (MIT) students may sign up for her freshman chemistry class grudgingly and only because it is required. After all, when she began her undergraduate studies at Vassar College, she thought chemistry had no relevance to her two intended majors: drama and biopsychology. "I wasn't even sure what biopsychology was, but it sounded good," says Drennan, now associate professor of chemistry. "When they insisted I had to take chemistry, I thought it was so unfair."

But she took the required course and fell in love—hard—with the beauty of chemistry. She grew fascinated with the molecular details underlying biological systems and wound up majoring in chemistry. "I'll admit that the basic principles are not that exciting in and of themselves," she says, "but chemistry is at the heart of biology."

After college, Drennan spent two years teaching high school science and drama at a Quaker boarding school in the Midwest that doubled as a working hog farm. But she realized her passion to know how things work could be satisfied only by a research career. Now Drennan's studies drill down to the structural basis of how molecules work, as exemplified in one of her recent research articles that answers a mystifying question about how nature tailors a complex antifungal agent.

Dislike or fear of chemistry, especially by biology students, is a major problem that will have an impact on the future of biological science, she says, citing a National Academy of Sciences report that too many biologists are successfully avoiding chemistry in their training. "How can we understand the complexity of macromolecular machines, for example, without employing physical chemistry?" she says. "I always thought that biology was more interesting than chemistry, but even in biology, students have to have a chemistry background to make real contributions."

In hopes of inspiring her students to take chemistry courses beyond those that are required, Drennan plans to expand the range of biological examples she already slips into her lectures for the freshman chemistry course she co-teaches. Now, she uses vitamin B12—a personal molecular favorite—so often that students start laughing every time she mentions it. "If you give me a topic, I'll find a way to use B12—acid/base, oxidative reduction," Drennan says.

She even shows a movie created by colleagues that demonstrates how the B12 enzyme has to change its shape to do its job. The molecular action on the screen is set to the tune of "Shake, Rattle, and Roll."

"That's what it's all about—chemistry in action," she says.

Drennan tells her chemistry students a story about her dad, a medical doctor who read one of her research papers and asked how folic acid could reach an apparently sealed-off part of the B12 structure in a crucial reaction. "It was a great question," she says. "It's a simple question, but it gets people thinking about, how does that work? Then they are eager to see the experiments we did to answer that question."

As an HHMI professor, Drennan plans a "boot camp" for graduate students and postdoctoral fellows in chemistry to train them in teaching and mentoring skills and to help them incorporate biological examples into their teaching. Another part of her project involves support for the MIT Undergraduate Biochemistry Association. Drennan started the group to help compensate for lack of a formal biochemistry program at MIT. So far, more than 80 student members of the association have benefited from academic advice on interdepartmental course selection and research opportunities. The group also provides networking opportunities to help students find the right study partners, an integral part of the culture at MIT and a key factor in academic success.

SARAH C.R. ELGIN, PH.D.

Washington University in St. Louis

St. Louis, MO

Sarah Elgin's research focuses on elucidating the mechanisms of heterochromatin formation in *Drosophila* and mapping chromatin features across the genome to further our understanding of epigenetic regulation. Assisting her along the way are teams of undergraduates who collectively analyze regions of the heterochromatic fourth chromosome of *Drosophila*, the so-called dot chromosome. Elgin has used her HHMI professor award to create the Genomics Education Partnership (GEP), a collaboration between science faculty from primarily undergraduate institutions and the Genome Center at Washington University. The GEP provides students nationwide with an opportunity to participate in a large-scale genome sequencing and annotation research project and contribute to scientific discovery.

Sarah (Sally) Elgin remembers being drawn to science as a child because it offered a concrete way to understand the world around her. "I liked poking and prodding things," she says. "I wanted to figure how they worked." It's that joy in learning new things that has pushed Elgin to create a program that provides the same opportunity for her students at Washington University in St. Louis, Missouri.

Elgin does research on genomes, a field of study focused on the DNA sequence of individuals and organisms. In the past 15 years, high-throughput machines that can quickly determine an organism's DNA sequence have revolutionized the field, turning it from a lab-based field that looked at the genome one gene at a time to a computationally based field focused on large-scale data collection and analysis, a field now referred to as "genomics."

As the field became increasingly complex and data oriented in recent years, Elgin realized that her students no longer had the same sort of easy access to the science that she loved as a kid. Biologists often spend their days studying numbers on computer screens, not microscope slides or fruit flies wriggling with life.

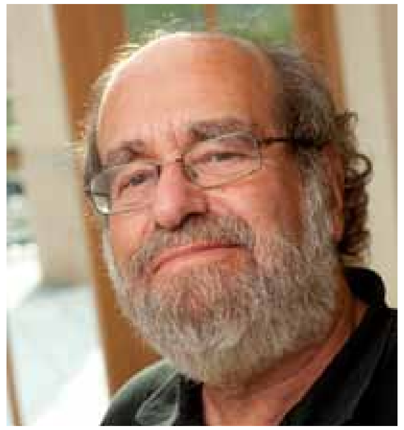
Elgin thought she could motivate students by having them play a real role in the scientific process—not just sitting in a classroom jotting down notes—so she decided to develop a curriculum to do just that. "The goal is twofold. One is to bring more genomics into the undergraduate curriculum, most of which was written before we knew how to sequence genomes. The other goal is to do it in such a way that students are actually involved in the research project," she explains.

The result is a research-based course; students learn to work with large data sets and interact with the university's Genome Sequencing Center in transforming a genome's raw sequence data into a more polished, finished sequence and then analyze the information in that sequence. The task of sifting through mountains of data to find relevant information requires both brute force and brainpower. "Think of a genome like a copy of *Moby Dick*—but instead of being its usual thick volume, it's 20 times longer because someone has inserted gibberish at random places," Elgin says. "Our job is to find the sentences." Computers have become good at finding the "words" within a genome, but they often fail to construct good sentences. The students analyze the computer output and learn to use several lines of evidence to construct testable models of genes and chromosomes.

As she was developing and testing the curriculum, Elgin quickly realized there was so much interesting work to do that the class could become a nationwide effort that provided a research experience for students across the country. With the help of her colleagues at Washington University, that vision became the Genomics Education Partnership (GEP), which Elgin began in 2006 with her second HHMI professor grant. The partnership now includes more than 60 colleges and universities across the country that provide students the opportunity to work on large-scale DNA sequencing projects.

The work is challenging in its own right, but it also offers students an opportunity to move the science forward. The results of the students' work serve as a foundation for papers that Elgin and others submit for publication in research journals; two journal articles based on the scientific research have been published since 2006. The information also goes into a national database that scientists use for their own research. In addition, GEP faculty have published two papers in the science education literature to help others adopt this style of teaching.

For students, the chance to do something that matters is an incentive to do top-notch work. Currently, the project focuses on the fruit fly's dot chromosome, which may hold important information about genome organization and gene expression. "Students are so excited to do something that doesn't end up in the wastebasket at the end of the semester," says Elgin, who also serves as an advisor for HHMI's Science Education Alliance. "They've been apprentices for so long, and they're just dying for the chance to do something real."



IRVING R. EPSTEIN, PH.D.

Brandeis University
Waltham, MA

Irving Epstein's lab studies complex, nonlinear chemical systems that display periodic oscillation, chaotic, and wave propagation behaviors. As a scientist who understands the importance of engaging students' fascination with science, he has leveraged his HHMI professor award to develop the Science Posse at Brandeis University, a mentoring program that recruits and trains students from inner-city high schools to help improve their success in science. Expanding now to recruiting networks in New York City and Boston, the program's current Science Posse scholars participate in identifying and mentoring new recruits and will play leading roles in creating a Biology Olympiad for Boston-area middle school students.

Borrowing from the slang of the Old West, inner-city youth sometimes refer to their groups of friends as "posses." In academic circles, New York's successful Posse Foundation has given the word a new meaning: a group of inner-city high school students trained as leaders and role models and then enrolled at top colleges and universities.

Now chemist Irving Epstein is collaborating with the Posse Foundation to bring "science posses" to Brandeis University in Waltham, Massachusetts—in addition to the 10 Posse Foundation students that already enter Brandeis each year. He has worked with the foundation to develop a program that focuses on science, and he now seeks to propagate the Science Posse concept to other universities across the country.

"We take kids who, on paper, look like they can't succeed in science and help them to do just that," Epstein says. Thus far, he has revamped Brandeis's student selection process to take into account the potential of the science posse candidates, developed a college preparation course for high school seniors, and added a two-week on-campus summer "science boot camp" for entering freshmen. "We train students in the culture of science before their first day of classes, and, judging by the performance of our first two Science Posses, it's made a huge difference," says Epstein, who is also starting two new programs to entice high school juniors and middle school students into science.

Epstein has not only sought to attract inner-city students—most of them underrepresented minorities, first-generation college students, or both—into science, he has also worked to prevent unexciting introductory chemistry courses from driving students away from science majors. A chemist who pioneered the systematic design and study of oscillating chemical reactions—research with practical applications in biology and many other fields of science—Epstein clearly finds chemistry anything but boring. "General chemistry, for many students, is seen more as an obstacle, instead of something that's intellectually interesting," he points out. So, based on student feedback, Epstein modified the general chemistry course to reduce lecturing and maximize fun, including visual demonstrations, hands-on experience, and computer games.

Epstein is the ideal scientist to bring fun into the classroom. Thirty years ago, he was looking for a summer project for an undergraduate when he stumbled across an article about pattern formation in chemical systems. It turned his life around, in the lab and the classroom. He changed the focus of his research from quantum mechanics to pattern formation and nonlinear dynamics, and ever since he has been using chemicals in his classes that, when combined, result in striking swirl patterns or rhythmic changes from one color to another.

"This kind of behavior is eye-catching and makes students wonder about its causes," he explains. "If they can understand why chemicals behave this way, we can get them thinking and asking questions like scientists."

JO HANDELSMAN, PH.D.

Yale University
New Haven, CT

Jo Handelsman's pioneering research focuses on the genetic and functional diversity of microorganisms in soil and insect gut communities, including metagenomics approaches to study uncultured bacterial communities. Handelsman is nationally known for her efforts to improve science education and increase participation of women and minorities in science. She has promoted standards for "scientific teaching," an evidence-based approach to teaching science, through programs such as the Teaching Fellows programs at the University of Wisconsin–Madison and Yale and the National Academies Summer Institute for university faculty. To support broader training and dissemination, she is developing the Scientific Teaching Toolbox, a web-based resource for biology instructors.

After speeding through college and graduate school, Jo Handelsman became a professor of plant pathology at the University of Wisconsin–Madison when she was just 26. "I was so unprepared," Handelsman recalls with a shudder. "We are extremely well prepared to do research. But that's not all we do as faculty."

She had no training for perhaps the scariest task of all: teaching. When Handelsman first entered the classroom, she lectured at her students, like most of her colleagues before her. "We all go into the classroom and simply do what was done to us. That's not a very scientific way to go about it," she says. "We would never do that in our research."

As she stood terrified in front of those students, Handelsman had no idea that, two decades later, she would be known nationwide for her efforts to improve science teaching.

The gap between what Handelsman was telling students—a lot—and what they were taking in—very little—became clear when she started teaching a class for 30 undergraduate nonscience majors. The breaking point came when she tried to teach the students how to prove that a microbe was the cause of a disease. "It just felt so dry, so mechanical, that I finally said to them, 'You guys just have to do this.'" At the next class, Handelsman arrived with Petri dishes, toothpicks, and sick plants. "At first, they all just stared at me and had no idea of how to proceed. I told them to talk to each other." The room erupted. "They were acting just like scientists," Handelsman recalls proudly. "That was the moment that I realized that there really is another way to teach."

Handelsman calls that way "scientific teaching." She draws on evidence-based studies to create a "toolbox" to improve undergraduate science teaching, such as active learning, mentoring, classroom diversity, and self-correction through feedback—lessons she has developed since her appointment as an HHMI professor in 2002. A good lesson incorporates the best aspects of science itself: the rigor, creativity, and dynamism of a scientific community and the thrill of the experimental chase, she says.

As an advocate for teaching reform, Handelsman has been a regular co-organizer of the Summer Institute on Undergraduate Education in Biology, sponsored by the National Academy of Sciences and HHMI, among other organizations. The intensive, week-long course brings together faculty from universities across the country to work on integrating research and modern learning techniques into classes that help students understand how scientists think.

Handelsman moved from Wisconsin to Yale University in January 2010. She says her reappointment as an HHMI professor will allow her to sharpen her scientific teaching "toolkit" and promote its use through the Scientific Teaching Fellows Program and the Summer Institute. Graduates of these programs will be dispatched as ambassadors to regional Summer Institutes that planners hope will spread the word about scientific teaching nationwide.

She also hopes to take on the issue of faculty diversity. Since white men are the norm among faculty on most college campuses, women and people from minority groups sometimes feel out of place, Handelsman says, an attitude that she has seen reflected in counterproductive ways in science classrooms. To try to address the origins of those feelings head-on, Handelsman will work with the drama schools at both Wisconsin and Yale to create and perform short plays that dramatize diversity issues in the classroom and provoke discussion among science faculty and students.

GRAHAM F. HATFULL, PH.D.

University of Pittsburgh

Pittsburgh, PA

Graham Hatfull is an internationally recognized expert in viral evolution and molecular biology of mycobacteriophages and their bacterial hosts. He has created the Phage Hunters Integrating Research and Education (PHIRE) program, a platform for high school and undergraduate students to gain authentic experiences in discovery research. PHIRE students identify novel mycobacteriophages and analyze their genomes. The excitement of discovery and the power of project ownership motivate students to tackle more challenging tasks, so Hatfull is expanding PHIRE to include opportunities for students to design their own experiments and pursue open-ended investigations into the bacteriophages they have discovered.

Graham Hatfull knows from personal experience that straight A's are not the only path to a research career. "I was the kind of kid who was average academically, to put it nicely. I didn't worry that much about it," he says. But that changed when, as an undergraduate at the University of London, Hatfull became intrigued by an independent study project on the peculiar properties of blue-green bacteria. In fact, he was so enthralled that he spent the next two summers living in the dorms and surviving on cheese sandwiches to complete the unpaid project.

Years later, as a professor and department chair at the University of Pittsburgh, he finds that experience still shapes his educational philosophy: Science should be open to any student of any age or potential whose imagination could be ignited by doing research.

In 2000, when a high school teacher from nearby Latrobe, Pennsylvania, asked him if two of her students could be involved in his research, Hatfull didn't give it a second thought. He put them to work isolating new bacteriophages—viruses that can infect mycobacteria, the type of bacteria that can cause human diseases such as tuberculosis. "I saw no reason why they shouldn't be fully involved in a research project" rather than washing test tubes, he says. And with that, the Phage Hunters program was born.

In the PHIRE program (Phage Hunters Integrating Research and Education), students isolate phages from soil, purify their DNA, and then sequence it to reveal the organisms' genome. Hatfull says that PHIRE works for any novice scientist—student, teacher, or politician—because it doesn't require academic brilliance as defined by academic test taking, just a desire to follow where curiosity leads. He hopes this type of introduction to research will expand the diversity of the people who do science.

PHIRE offers high school and undergraduate students a chance to get their hands dirty—literally—and find out if research interests them. Starting with tactile tasks like collecting soil, adding buffer, and plating phages on Petri dishes gives students a concrete foundation. Then, when the research transitions toward the more abstract concept of a genome, the rush of genomic letters coming out of the computer isn't as intimidating, Hatfull says. "The toughest part of education is teaching concepts that are abstract and hard to understand."

Hatfull's PHIRE program has provided the framework for the first nationwide effort by HHMI's Science Education Alliance (SEA), which the Institute hopes will become a resource for science educators nationwide. SEA's National Genomics Research Initiative will have introduced phage hunting to college freshmen at 44 universities around the country as of fall 2010 through a year-long, research-based course. Hatfull serves as lead scientist for the project, which has been popular with students and faculty alike.

During the next four years, Hatfull proposes taking PHIRE to the next level—letting students' projects evolve to testing hypotheses about how interesting genes found in the phage genome might operate. Advances in DNA technologies now let phage hunters ask questions about which genes are most important to the phage, what those genes control, and whether a particular gene affects the mycobacterium host in some way.

"If this works well, we'll have the best of both worlds: the initial discovery part, which levels the playing field among students, and a foundation for doing hypothesis-driven experimentation," he says. "The PHIRE program is very much about lighting fires and inspiring kids to do science."

RICHARD M. LOSICK, PH.D.

Harvard University

Cambridge, MA

Richard Losick's lab studies differentiation, morphogenesis, and multicellularity in the spore-forming bacterium *Bacillus subtilis*. An internationally recognized microbiologist and elected member of the National Academy of Sciences, Losick values his connection to a broad community of scientific colleagues. As a science educator, he appreciates the powerful effect of engaging science students in mentored research early in their undergraduate years. He leveraged his HHMI professor grant to create the IDEAS (Increasing Diversity and Education Access to Sciences) program, providing a unique entry point for first-year Harvard students who have had limited opportunities to pursue their interest in science. His Life Sciences 100 program engages teams of students in hands-on experimental inquiry in faculty laboratories, an emerging model for undergraduate research at leading research universities.

When Richard Losick was an undergraduate at Princeton University, he made what he calls an "obscure" discovery that served as the foundation for his senior thesis. "It didn't make it into a journal," he recalls. "But no one knew it before me, and that really excited me about science."

What made the experience so valuable was having a mentor who pushed him to succeed. "My mentor went through my senior thesis in great detail," he recalls. "It was fantastic that he cared so much to look very closely at what I had written and to give me feedback about it."

Losick, now a biology professor at Harvard University, says the attention encouraged him to pursue his career as a biologist studying the cellular changes that govern microorganisms.

That early experience led Losick to realize that a mentor's personal attention can help persuade a student to become a scientist. As a professor, Losick had always set aside time to mentor talented students, and he often served as matchmaker for professors and students he believed would work well together. But he remained eager to encourage these mentorships on an even wider scale.

In 2002, with the help of his first HHMI professor grant, Losick developed two programs to bring faculty and students together into mentoring relationships. "A practicing scientist can mentor students on what matters most—learning how to learn, deciding which courses will serve them best, and showing them the excitement of doing research," he says.

The first program, Increasing Diversity and Education Access to Sciences (IDEAS, formerly called FEEDS), pairs first-year students at Harvard with faculty members for research projects that students pursue for the remainder of their undergraduate careers. Students receive a stipend for their research work, allowing them to spend their hours in the science lab instead of at mundane jobs. IDEAS fosters a community among the students, including by means of an annual retreat. A total of 54 students have participated in the program during its first seven years. Of the 30 students who have graduated, almost all are pursuing advanced degrees in science or medicine.

The second program, Life Sciences 100, aims to build closer ties between students and faculty by bringing together teams of undergraduate students to work on semester-long research projects led by a faculty member. Recent projects have included mapping neuronal circuits in zebrafish brains and studying electrical current production by microbial groups. At the conclusion of the project, students present their findings and learn to write National Institutes of Health–style grant proposals. More than 250 students, including a high proportion of women and nonscience majors, have participated in the program.

Losick's 2010 HHMI professor grant will help him build on both programs. The IDEAS program will expand to other universities, creating a larger community of students who will interact with each other annually at the retreat. Life Sciences 100 has expanded to include a range of cross-disciplinary projects, and Losick plans to share the program's success with a national audience.

While many of his students pursue careers in science after they graduate, Losick says the lessons they take with them apply no matter where they end up. "Students learn how to decide what's real and what's not by evaluating data," he says. "And I think that's a skill that everyone can use."

DIANE K. O'DOWD, PH.D.

University of California, Irvine

Irvine, CA

Diane O'Dowd's research focuses on understanding the cellular mechanisms that underlie learning and memory formation. As a neuroscientist nationally recognized for her teaching and mentoring, O'Dowd extends her scientific interests to her classroom interactions with undergraduate students and to her mentoring style with graduate students, postdoctoral fellows, and faculty colleagues. She has designed novel curricular strategies for active learning in undergraduate biology courses and has introduced students to the thrill of original scientific discovery. She is helping current and future faculty maintain productive research careers while teaching more effectively in the large lecture-style classrooms prevalent at research universities.

Students in Diane O'Dowd's introductory biology course never know what they are going to get. One day she might arrive toting tennis balls that stand in for hydrogen ions or show up in class wearing her daughter's old Halloween wig, which doubles as a membrane vesicle studded with spiky purple proteins. And dozing off in her class can be dangerous. A sleepy undergrad can wind up starring as the "resting neuron" in a one-act play on nerve-cell stimulation.

These are just a few of the ways O'Dowd has brought microscopic processes to life for students in large introductory lecture classes. Her "garage demos"—so called because that's where she forages for many of her materials—earn rave reviews not only from students but also from viewers on YouTube.

O'Dowd, a neurobiologist, began experimenting with the use of interactive teaching in small classes at the University of California (UC), Irvine, about 10 years ago. She found it was more fun for her and more effective for students than traditional lecturing. When she got the chance to develop a new introductory biology course in 2004, she and three fellow professors jumped at the challenge of creating the same interactive environment in a four-section monster course that would serve 1,600 incoming freshmen each fall. Among many other techniques, O'Dowd and her colleagues placed students into small in-class working groups and used hand-held electronic clickers to get immediate feedback on questions posed in class.

With funding from her HHMI professor grant in 2006, O'Dowd began looking for new ways to make sure students are actively involved, which led her to create the garage demos. O'Dowd studies the neurons and connections that account for learning and memory in fruit flies, and she regularly brings research into her classroom. For example, when discussing study strategies, she tells her students that the fruit flies she works on in her lab remember information in much the same way that humans do. The flies can be trained to avoid an odor by pairing it with unpleasant stimuli, like electric shocks. More importantly, she explains that long-term retention of the association requires repeated exposure to the pairs of stimuli interspersed with intervals of rest. While the flies can learn quickly if they "cram"—receiving paired stimuli with no rest intervals—they, like their undergraduate counterparts, soon forget what they learned.

The students are not the only ones who benefit. O'Dowd says she gets more satisfaction from teaching than in years past. Inspiring young people provides rewards that are different from those associated with her research but that complement it. "I love teaching, but I want to do it in the context of my research," she explains. "Students really listen when you tell them about recent discoveries. That's one bonus they get by attending a research university. The challenge is creating an environment where faculty are rewarded and enabled to excel in both research and teaching."

With her new HHMI professor grant, O'Dowd will use her introductory biology course as a model to promote techniques to engage students in large core classes, not only at UC Irvine but also at other large research universities. She says that faculty can improve the quality of instruction for students while reducing the time spent away from the lab. She and her team will also continue efforts to train teaching assistants to lead discussion sections in an interactive way and coach them on mentoring undergraduate research.

BALDOMERO M. OLIVERA, PH.D.

University of Utah

Salt Lake City, UT

Baldomero Olivera's research focuses on molecular mechanisms that underlie nervous system function, characterizing novel neurotoxins that target specific neuron receptors and ion channel complexes. These neuropeptides come from the venom of *Conus* species, predatory cone snails ubiquitous in the oceans surrounding his native Philippines. Elected to the National Academy of Sciences in 2009, Olivera takes a long view on training future generations of scientists, developing activities to engage the imagination of elementary and middle school students in the United States and Philippines. Drawing on the fascinating biology of cone snails, his Chemistry to Biodiversity project engages young students in hands-on science that encourages them to explore local biodiversity and cultural traditions.

Growing up in the Philippines, Baldomero "Toto" Olivera recalls that cone snails were sold by the kilo in local seafood markets. As a child, however, Olivera was unaware of the impact the predatory cone snail, *Conus magus*, would have on his life's work. Nor could he have imagined that the creatures would even enable his lab to develop a drug to bring relief to people in chronic pain.

Olivera—nicknamed Toto by a cousin who could not pronounce Totoy, a pet name sometimes given to Filipino boys—is now Distinguished Professor of Biology and a neuroscientist at the University of Utah in Salt Lake City. As an HHMI professor, he plans to take the story of the cone snail back to the children of the Philippines and the nearby Pacific islands that the snails inhabit. "These snails have so much potential, and the children don't know anything about their biology," he explains.

Olivera will teach children and undergraduates from the Philippines, Hawaii, and U.S. territories in the Pacific about the richness of their surroundings through a project he calls the Biodiversity-Biomedical Links Initiative. "My idea is to concentrate on the biodiversity that's at their feet," he says. His goal is to interest young students by educating them about scientific principles they can observe in organisms that they see every day.

And Olivera is well aware now that the fish-hunting cone snail, with its intriguing eating habits, is a good place to start. The snail harpoons fish with a radular tooth, a hypodermic needle-like structure that injects a paralyzing venom made up of 100 different components. Once the fish is harpooned and paralyzed, the snail reels it in and eats it.

By studying the complex neurotoxic venom made by the snails, Olivera and members of his lab have identified several drug candidates and gained a better understanding of how ion channels work. Michael McIntosh, now a fellow researcher in psychiatry at the University of Utah, was an undergraduate in Olivera's lab when he discovered a cone snail toxin whose synthetic form is now used to treat pain effectively in patients who have become tolerant to morphine.

Olivera believes the future of neuroscience depends on collaboration across disciplines. So he also plans to work to increase the number of students fluent in neuroscience by implementing an Interdisciplinary Undergraduate Neuroscience Program at the University of Utah. Students whose majors range from math to electrical engineering will be offered the opportunity to minor in neuroscience. "If we are to accelerate the pace of scientific progress, we need people looking at the same problems from different intellectual viewpoints," he says.

SCOTT A. STROBEL, PH.D.

Yale University

New Haven, CT

Research in Scott Strobel's lab focuses on biologically critical reactions catalyzed by RNA, including RNA splicing and ribosomal peptide bond formation. An award-winning scientist and educator, Strobel seeks to help students understand the process of scientific inquiry and experience the sense of ownership that comes with discovery research. His Rainforest Expedition and Laboratory (REAL) course provides unique opportunities for Yale undergraduates to participate in international research to collect and characterize novel endophytes native to South American rainforests. The opportunity for discovery inspires REAL students to develop their own assays to identify active compounds with potential applications for human health and the environment.

Students may spend years deciding whether to pursue a career in science. But Yale University biophysics and biochemistry professor Scott Strobel says he can determine with pinpoint accuracy what they'll decide to do by listening for a single word during their research presentations. "Students who use the word 'I' or 'we' to describe their research are typically more engaged than those who distance themselves from the research by talking about what the postdoc or PI wanted them to do," he explains. "It's as though the work is anyone's but theirs." Students who own their projects tend to stick with science; the rest can't seem to find the exit door fast enough.

Strobel—who nearly abandoned biology himself after an unimaginative high school teacher forced him and his classmates to memorize the scientific names of tapeworms—believes the best way to retain good students in science is to give them control of their research and make it relevant.

It was the idea of project ownership that drove Strobel to develop the Rainforest Expedition and Laboratory (REAL), which first received HHMI funding in 2006.

Through REAL, 16 students each year do research on endophytes—fungi that live on plants and have the potential to serve as everything from medicines to biofuels. Because endophytes remain relatively unexplored by the scientific community, students know that their work has a real chance of breaking new ground, says Strobel. "It's not beyond the scope of possibilities that every student will discover a new genus of fungi." By taking students to one of the most biodiverse rainforests in the world, he provides them with almost endless opportunities to unearth something new.

The program, which starts during the spring semester and lasts through the summer, takes students from New Haven to the jungles of Coca, Ecuador, and back. Students work their way through a series of increasingly challenging objectives. They begin by creating a plant collection list for their travels; then they identify and collect samples during a two-week trip to Ecuador's Yasuni National Forest. After returning to Yale, they isolate and characterize the organisms through DNA sequencing, phylogenetics, and bioinformatics techniques.

During the first four years of the project, some 70 students isolated several hundred microbes, about 10 percent of which are novel at the genus level. Strobel and his students have given scientific names to some of the organisms and have published work in a number of journals. But Strobel says that publishing is just one measure of success. "One student has gone on to isolate endophytes in Borneo with the help of a fellowship and others have decided to pursue Ph.D. and M.D./Ph.D. degrees in related fields. One entrepreneurial student wants to start a company based on his work," he says.

More important, such diverse and promising outcomes suggest that students see science as more than a body of facts to memorize, says Strobel. "Students develop confidence in their abilities. They realize that science is a way of thinking and approaching problems."

When he's not working to grow the REAL program, Strobel does research that explores the links between chemical and structural biology. His work focuses on RNA splicing and ribosome-catalyzed peptide bond formation as well as biofuel production from some of the organisms isolated by the students.

With HHMI's most recent renewal of funding for REAL, Strobel plans to expand its reach. While the program will continue to fund 64 students from Yale over the next four years, Strobel will also work to build partnerships that will give other schools the tools they need to set up similar programs to study endophytic biodiversity in nearby forests or parks. "We've got one partner now, Johns Hopkins, but we'd like to set up a program that will allow other schools to do this, too," he says.

In the end, Strobel says the students' REAL work is far more challenging—and important—than anything they could learn in a textbook. "With REAL each student starts at the beginning," he says. "They literally pull out things from the field that nobody has ever seen before—new organisms, new species, new genera. Everything is theirs to observe for the first time, and they're the ones making discoveries. It's great to see students get excited about what they're learning."

GRAHAM C. WALKER, PH.D.

Massachusetts Institute of Technology

Cambridge, MA

Graham Walker's lab studies proteins involved in cellular response to DNA damage as well as mechanisms of bacterial–host symbiosis. Walker was intrigued by the idea of applying a scientific research lab model to build research teams for training future science educators. The result was the Education Research Group at the Massachusetts Institute of Technology, charged with developing tools and curricula for undergraduate biology training. The group's efforts include StarBiochem and StarGenetics, student-friendly applications for learning molecular biology and biochemistry. The group's graduate and postdoctoral members participate in a variety of teaching and educational projects and play leadership roles in the continuing development and dissemination of educational resources for biology.

Graham Walker knew the Massachusetts Institute of Technology (MIT) was different. But he was still surprised when he arrived for a job interview in Cambridge in 1975 to discover that MIT was serious about teaching undergraduates. "Honestly, I was so excited at the end of that first day that I couldn't sleep," he remembers. Walker's love of teaching had not been much of a factor in his previous interviews, but at MIT he thought he could talk about his interests. "I felt like a lucky star had hit me on the head."

Walker started his teaching career by guiding MIT students through introductory lab courses and then switched to teaching advanced undergraduate research labs. "Lab courses were where I learned to teach because that's where I began to understand what students don't know about biology," Walker recalls. Now he leads a large introductory biology course once taught by Nobel Prize winner Salvador Luria.

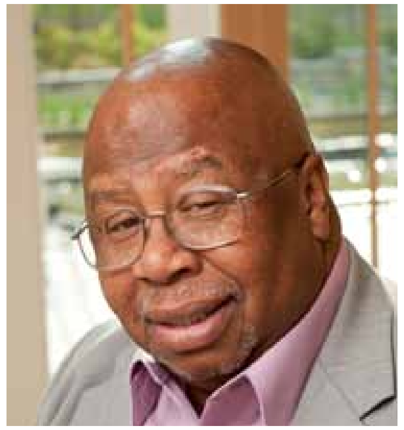
Along the way, Walker realized that something important was missing in science education: research. "I thought, 'Why don't I form an education group that's modeled after a lab research group?'" In 2002, with help from his HHMI professor funding, Walker hired three postdoctoral students to join a team focused on science education research.

The group held regular lab meetings that were open to the MIT community, and soon dozens of faculty and graduate students were attending regularly. They talked about ways to make teaching easier and more accessible at all levels. Those discussions resulted in a wave of projects, including a "teaching toolkit" for MIT teachers and graduate students, a curriculum for high school field trips that stressed the use of primary literature and evidence-based teaching methods, and a strategy for organizing and prioritizing the key ideas in a biology curriculum.

The research group also brainstormed which biology concepts were important to modern science but hard to convey to students. One important topic was how to get students to understand the three-dimensional structure of proteins using "protein viewers," sophisticated molecular visualization engines that help scientists see how proteins are folded and how they work inside cells. Most protein viewer programs were too sophisticated for beginners but Walker believed that "playing with a protein" was exactly what new students needed to grasp how molecular biology works. At first, Walker tried unleashing his first-year students on an advanced protein viewer by providing elaborate instructions. "That was a disaster," he recalls. Creating a simpler interface for an existing viewer proved to be too hard to implement. Then, one attendee at the education group meeting, Chuck Schubert of MIT's Office of Educational Innovation and Technology, suggested that they build their own protein viewer with a custom interface that was based on the principles of protein structure the students learned in introductory biology courses. That became StarBiochem.

Released in 2006, StarBiochem is a powerful protein viewer with a simple interface that has been used by more than 3,000 undergraduates and high school students in classes and accessed online more than 15,000 times by students and teachers from 71 countries. StarBiochem's success led to StarGenetics, an interactive simulator that models genetic crosses, and plans to build StarCellBio, a simulator for cell biology experiments.

With his new HHMI professor grant, Walker wants to reestablish his science education group with two postdoctoral students interested in science education. Among the projects he wants to tackle is understanding and better using videotaped lectures, which could have important implications for online teaching and for large lecture classes. Walker's own introductory biology course went online in 2006 and has been viewed 400,000 times on MIT's OpenCourseWare web site and YouTube and downloaded 50,000 times through iTunes. Between a quarter and a third of his 198,000 YouTube viewers watched the entire series. Walker wants to understand why. "I don't think you download a lecture series by accident," he says.



ISIAH M. WARNER, PH.D.

Louisiana State University

Baton Rouge, LA

Isiah Warner's lab focuses on developing improved technologies for studying complex chemical systems. An award-winning analytical chemist with several patents to his name, Warner is a role model to students interested in applying basic science to improve lives. As an African American who pursued his studies with limited scientific role models for himself, he understands the importance of mentoring students to achieve their full potential. Warner created a "hierarchical mentoring" model that integrates research, education, and peer mentoring for precollege and undergraduate students to succeed and advance in science, technology, engineering, or math disciplines. The model is expanding to include additional research opportunities for Louisiana State University students and applications in international settings.

Son of a housekeeper and a longshoreman, Isiah Warner has been a scientist since age two, when he conducted his first experiment: tasting kerosene to find out why it produced light in a kerosene lamp. A quick trip to the hospital interrupted his investigations, but he was back at the lab bench by the age of 10, when his parents gave him a chemistry set.

Warner, who grew up in rural Bunkie, Louisiana, spent his summers working in the cotton fields to earn extra money for his parents and playing with the chemistry set when he got home. But as an African American in the Deep South in the early 1960s, he had few role models to show him how to turn his backyard chemistry experiments into a career.

A high school English teacher was among the first mentors to encourage his interest in science. She pointed him toward a summer chemistry program at Southern University, an HBCU (Historically Black Colleges and Universities), in Baton Rouge, Louisiana. A few years later, when Warner was a freshman at Southern, the chair of the chemistry department convinced him to major in that subject. "At points in my life when I've been in a quandary, there have been people showing me the way," Warner says. "Those were my mentors, and without them I wouldn't be where I am today."

Now a professor at Louisiana State University (LSU), Warner is a prolific analytical chemist who has also won accolades for his teaching and mentoring. In 1997, Warner received the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring from President Bill Clinton.

With help from his 2002 HHMI professor grant, Warner set up a formal mentoring program aimed at first-year science, technology, engineering, or math (STEM) undergraduates who show promise but are struggling with their courses. Warner assigns them to a faculty or graduate student mentor who, in turn, is guided by Warner and other faculty members on how to support a young student. "The first year of an undergraduate STEM major is a critical time," Warner says. "If they do not do well that first year, it is often very difficult for them to recover, and many students drop out of STEM as a result."

Warner sees that work as "paying forward" the mentoring he received in his youth. The beneficiaries include biochemist Michael F. Summers, an HHMI investigator at the University of Maryland, Baltimore County, who went to Warner for advice when he wanted to set up his own program to boost African Americans' participation in science. "Isiah has been an outstanding mentor and role model, not just for the large number of minority students he has mentored, but also for nonminority faculty who want to have a positive impact on the retention and mentoring of minority science students," Summers says.

Teaching students how to be good mentors is built into Warner's program. Undergraduates reinforce their scientific skills and commitment to research by mentoring younger students. In the past few years, the program has been extended to reach students in Louisiana's community colleges and high schools. Many of the participating students in the undergraduate, community college, and high school programs come from groups traditionally underrepresented in the sciences. Warner and his colleagues have been pleased that their mentored students' rate of graduation with STEM degrees has been about double the LSU average.

With a recent renewal of his HHMI professor grant, Warner will add an international dimension to his initiatives. Mentored STEM undergraduates and other LSU students will have the opportunity to do research at HHMI's KwaZulu-Natal Research Institute for Tuberculosis and HIV (K-RITH) in Durban, South Africa. "Our students often need to expand their horizons, and research abroad is an excellent mechanism for doing so," Warner says.

Photos: *James Kegley*
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