

Bold Experiments

The 2014 HHMI professors are bringing innovation from the lab into the classroom.

BY ERIN PETERSON

SUSAN S. GOLDEN



BRIAN R. CRANE



MARK GOLDMAN



AYDOGAN OZCAN



TRACY L. JOHNSON



ARIEL D. ANBAR



ILLUSTRATED BY
THEA BRINE

SUSAN K. MCCONNELL



ANDREW MURRAY



MUHAMMAD H. ZAMAN



JEFFREY S. MOORE



JANE KONDEV



DAVID R. MARCHANT



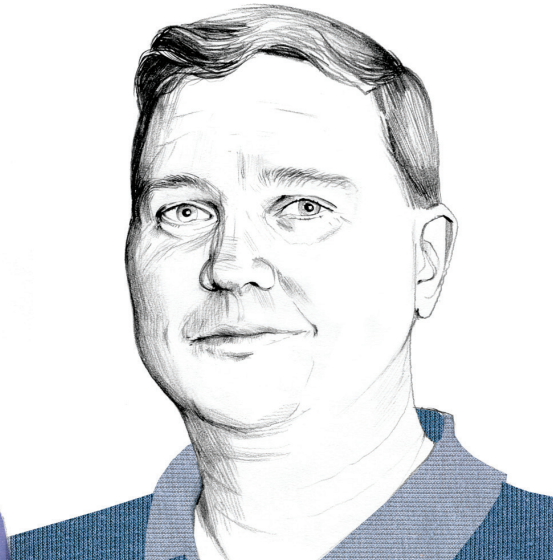
CHRISTOPHER D. IMPEY



ANNE J. MCNEIL



JOSEPH M. JEZ





ANNE MCNEIL
University of Michigan

Project: Building meaningful labs—and crowdsourced data—into first-year organic chemistry.

UNIVERSITY RESEARCH SCIENTISTS are expected to be pioneers in their labs. A new group of HHMI professors will be meeting those same high expectations in the classroom.

The traditional systems of rewards and recognition and allocation of resources at research universities often encourage an imbalance: most science faculty members are far more focused on their work as research scientists than their work as educators.

“It has been a great, missed opportunity,” says Sean B. Carroll, vice president for science education at HHMI. “Research universities attract some of the brightest young minds in the nation, and they are home to some of the best scientists. They offer a potentially superb environment for engaging students in both the classroom and the laboratory.”

Since 2002, HHMI has been promoting a better balance between research and teaching by supporting some of the country’s leading research scientists who also engage students in the classroom as HHMI professors. A total of forty scientists given HHMI professor grants have applied the same kind of creative approaches and rigorous measurement in their classrooms as they have in their labs. They have demonstrated that top scientists can be top educators, by expanding and enhancing student research opportunities, finding innovative ways to offer mentoring, and encouraging other faculty to engage in effective teaching.

Fifteen additional researchers were named HHMI professors in June. Each will receive a grant for \$1 million over five years to continue to push science education forward through projects as varied as creative writing about science and group research projects via online courses.

With every approach, the professors strive to help students grapple with—and deeply internalize—authentic research and scientific thinking. “The HHMI professors push hard at the boundaries of science education. They raise the profile of the conversation about education,” says HHMI senior program officer Sarah Simmons. “The new professors leverage their credible voices in the scientific community to pull together the educational and research sides of science.”

Here are the stories of six of the new HHMI professors—top-tier researchers whose work ranges from biology and chemistry to geology and astronomy. Their work promises to bring the excitement of science into the classroom and fuel a new generation of STEM majors.

Anne McNeil knows the alarming statistic that more than 60 percent of students who enter college with an interest in a STEM degree fail to earn one.

She was suspicious that her school’s dry introductory organic chemistry laboratory, taken by 2,000 undergraduates at the University of Michigan each year, contributed to that failure rate. “The lab is really basic—things like titrations and separations—with essentially no organic chemistry,” she says. “It’s de-motivating for students.” Unfortunately, it’s an all too common introductory lab experience.

McNeil is committed to transforming her school’s lab from loathed to loved, and that process will start with biodiesel. Students will use the fairly simple techniques of refluxing and separation to transform used vegetable oil from local restaurants into biodiesel for use by local farmers. The techniques are simple and the results are meaningful. And the students, she hopes, will be hooked.

The experience won’t be a single paint-by-numbers lab. After following a standard “recipe,” students will spend the next lab changing a variable—temperature, solvent, concentration—and hypothesizing how the change will affect the outcome. By adding their data to a shared

spreadsheet, students will have access to a large dataset to make comparisons and draw conclusions.

As part of her organic chemistry lab overhaul, McNeil plans to include an array of other experiments, such as labs in which students extract natural rubber from milkweed.

“I want students’ initial lab experiences to inspire them to pursue other research opportunities.”

Concrete projects can boost students’ enthusiasm for—and desire to continue in—science, she says. As a first-year student in 1996, McNeil’s passion for science was propelled by a professor who drew parallels between abstract concepts, such as substitution reactions, and their real-world applications, such as the chemical weapon mustard gas. Today, McNeil’s research group develops sensors that help contractors and inspectors check for harmful lead in paint at construction sites. These chemical tools, known as gelators, may someday be used to find explosives at airport checkpoints or enzymes involved in certain diseases.

With the new lab projects, McNeil hopes that her students will see that labs are about discovery and problem solving rather than learning abstract concepts. “I’m trying to replicate the research experience—within the constraints of the system—for as many people as I can,” she says.



MUHAMMAD ZAMAN

Boston University

Project: Use real-world problems to help students understand global health issues in the context of biomedical engineering.

Muhammad Zaman believes it is not enough to give his students the tools to solve important global health problems. It's his responsibility, he says, to impress upon them the value of the work.

In his own research, Zaman and his colleagues have developed PharmaCheck, a technology that can quickly and cheaply detect

“We want students to grapple with global problems that speak to their social consciousness.”

counterfeit and expired antimalarial and antibiotic drugs, in part by revealing the concentration of active ingredients. *Scientific American* hailed the innovation as one of 10 “World Changing Ideas” in 2013.

Zaman wants to motivate students to develop similar practical global health solutions. He's developed a comprehensive program at Boston University to do that in different, and reinforcing, ways.

The first is an idea repository—a database of real-world problems that professors can contribute to and draw from to help make abstract concepts come alive for their students. Zaman cites a simple example from his own class: instead of having students calculate stresses on a beam, they calculate stresses on a wooden crutch for a disabled girl, or a metal crutch for a middle-aged man. “This is a real problem in Zambia, where disabilities are [common],” he says.

The second is bringing to the campus guest speakers who can discuss global health policy. Finally, he plans to send students to a biomedical engineering summer school at one of several schools in Africa to get firsthand experience with difficult global health problems.

The most important aspect, he says, is the integration of all of these components into a cohesive whole throughout the students' college careers. Students don't just tackle global health issues in a single course or summer. “We want ideas to be reinforced multiple times,” Zaman says.

His end goal is far more profound than creating the world's best engineers. “My job is to make them better citizens of society,” he says. “I want them to be people who are able to contribute to the society at large.”



SUSAN MCCONNELL

Stanford University

Project: Developing and expanding courses that help students merge art and science.

Growing up, Susan McConnell imagined herself as the next Jane Goodall. Goodall's grand adventures studying chimpanzees in Tanzania—and her captivating storytelling—cracked open the joy of scientific research for the young McConnell.

After receiving her PhD from Harvard University, McConnell found her own way to pursue scientific success. As a neurobiologist, she studies how neurons in the developing cerebral cortex are produced, assigned specific characteristics, and wired together into functional circuits.

But even from her lab, McConnell felt the tug of Goodall's larger vision. Great science was a starting point. Even greater power came from sharing the research in ways that inspire others to pursue and support it. “[Scientists] can't just write to other scientists,” she says. “We need to be able to communicate to the general public.”

That idea served as the catalyst for two new classes at Stanford: “Personal Essay in Biology” and “Senior Reflection in Biology.” Both courses allow students to bring an artistic sensibility to the science they study.

In the first course, students spend a term working with award-winning writer Andrew Todhunter to complete a personal, deeply researched scientific essay in the style of magazines such as *The New Yorker* or *National Geographic*. In the second, students use a visual medium of their choice—photography (McConnell's specialty), painting, or multimedia, for example—and spend a year working closely with faculty mentors in both science and the arts to create and polish their science-linked work for viewing in a campus gallery.

In pilot programs, one student wrote a gripping personal essay that combined research about the neurochemistry of mental illness and the story of her roommate's suicide. Another used sand animation to explore

“We must present stories about science that are accessible, engaging, and informative.”

the impact of parasites in local water sources in Ghana; she shared a version of the project at a TEDx event and earned a standing ovation.

McConnell says this twist on scientific thinking, through projects that she describes as “kind of ‘out

there’ alternative models,” has the potential to transform the way students think about the science they do and the way they share that work with others.

As an HHMI professor, McConnell plans to further develop and expand the popular programs, and add humanities students who are interested in using science as the foundation for their art. Communicating science in beautiful, accurate, and unexpected ways, she says, can help students wrestle with important problems.



TRACY JOHNSON

University of California, Los Angeles

Project: Develop a program that emphasizes mentorship and collaborative learning with a scalable, research-intensive course on RNA splicing as its capstone.

It's not easy for first-year biology students to picture the complex dance of cellular processes. That's why Tracy Johnson never relies on lectures as her sole teaching tool.

To help describe a classic experiment that demonstrated DNA's compact form within a cell, for example, she pulls students from their seats to have them represent the proteins central to this formation, uses yarn to represent the DNA, and then asks other students to play the enzymes that cut the DNA. "Doing it this way," she says, "led a whole new group of students to say, 'ah, I get it.'"

Participatory learning works, and that's why she's developing a new course that allows first-year students—drawn in part from high schools with sizeable populations of underrepresented minorities—to help her with her research. Johnson studies RNA splicing and how it is regulated.

During the year-long program, Johnson and about 25 students will work with *Saccharomyces cerevisiae*, yeast cells that have fast doubling times and important similarities to human cells. Students will perform open-ended genetic screens to help identify molecules that play a role in RNA splicing. The work will include in-depth faculty and

"Real science is collaborative."

peer mentoring—elements that help science stick, says Johnson. When students work together on these projects, they learn more than just the mechanics of the project. "They learn how to articulate and defend their ideas, and how to work collaboratively," Johnson says.

Using online data integration and analysis tools, students will connect the different data to develop testable models that describe the mechanisms of RNA splicing. The students will present their findings before an audience of experts. If the program goes well, Johnson hopes to share the module with other schools interested in having their students do research during their freshman year. For now, she wants to make sure that her students know that they're doing more than just absorbing knowledge: they're creating it. "Great lab courses offer authentic research experiences," she says. "Students generate data that can make an impact."



DAVID MARCHANT

Boston University

Project: To bring a few undergraduate students to Antarctica to study its landscapes—and to give thousands more a backstage pass to the work.

Geologist David Marchant has been studying climate change in Antarctica for decades, but until now, he's never been able to bring a team of undergraduate researchers along to help—that opportunity has typically been reserved for graduate students and postdocs.

But with the help of the HHMI professors grant, Marchant will take up to three undergraduates to Antarctica each year. "I'm taking undergraduates because I want to invest in them," he says.

"The success of the entire expedition might lie in their hands."

Students may initially be attracted to the sense of swashbuckling adventure that comes with studying

Antarctica's frozen landscape, but they're even more energized by the potential impact of the research.

Among other things, Marchant studies the world's oldest glacial ice. He measures atmospheric gasses over million-year timeframes to understand Earth's natural variability in carbon dioxide and examines the geologic record for ice loss. The National Science Foundation's U.S. Antarctic Program supports his fieldwork in Antarctica.

His new 18-month program starts with a class of about 15 students, from which Marchant will choose his research companions for Antarctic trips of up to eight weeks. Among the travelers' many research responsibilities will be to take super-high-resolution photographs of glacial features and collect samples of volcanic ash for radiometric dating. While students are in Antarctica, they also give talks about their work to distinguished visitors, including senators and CEOs.

Students who remain stateside will use the super-high-resolution photographs to create virtual field expeditions and perform real-time landscape analysis. Marchant will also develop a seminar course and a laboratory course in which students conduct geochemical analyses on Antarctic samples. A new website will give anyone in the world a virtual tour of the areas where he and his students work.

For those who travel with him to Antarctica, he says, the trip will have a lasting impact. With their fast pace and steep learning curves, these trips transform students into confident researchers in a few short weeks, he says. "You can see it when they're back [on campus], too. There's nothing you can give them after this experience that they'll fail at. They'll just keep trying until they get it."



CHRISTOPHER IMPEY
University of Arizona

Project: Bringing interactive learning and research to massive open online courses.

Astronomer Christopher Impey has been trying to answer big questions about the universe: How did galaxies grow to their current sizes? How do some of the universe’s most immense black holes grow?

But in the years to come, he’ll pursue his biggest, most audacious vision yet: harnessing the power of tens of thousands of student scientists to move his research forward.

“Students are capable of classifying galaxies [just] as well as PhD astronomers.”

In 2013, Impey launched his first massive open online course (MOOC) through the website Udemy. The course, “Astronomy: State of the Art,” attracted a stunning 14,000 students from 175 countries.

While the enthusiasm for MOOCs has swung in recent years from red-hot ardor to cool suspicion, Impey believes that the potential of MOOCs is only beginning to be explored. In his 27 years as a teacher, Impey has implemented several interactive techniques, including real-time comprehension surveys and hands-on group work. He’s ready to bring the most successful approaches to online learning.

Impey plans to build student participation into his online courses by adding real research and collaborative websites called wikis. He will replicate classroom lectures with short video lectures. Small online groups of students will agree to meet at a specific time; they’ll work together in real time to fill out wikis about the video’s topic, with the help of a facilitator.

As students progress, Impey will ask them to do modest—but real—research, for example, classifying galaxies, which come in diverse shapes and sizes. “Students get a set of archetypes to learn from,” he says. “They learn what makes a spiral, what makes an elliptical, how to recognize imagery, what symmetries to look for, and so on.”

Through these projects, Impey hopes to lead his students to the kind of “light bulb moments” that turn interactions into learning. “There’s a time in the classroom when groups get engaged in discussions, even arguments, as they try to assimilate unfamiliar material. It’s chaotic—a mixture of heat and light—where learning takes place,” he says. “I want to try to take those light bulb moments online.” ■

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—TRACY JOHNSON

2014 HHMI Professors

Ariel D. Anbar
Arizona State University
Tempe, Arizona

Brian R. Crane
Cornell University
Ithaca, New York

Susan S. Golden
University of California,
San Diego
La Jolla, California

Mark Goldman
University of California, Davis
Davis, California

Christopher D. Impey
University of Arizona
Tucson, Arizona

Joseph M. Jez
Washington University
in St. Louis
St. Louis, Missouri

Tracy L. Johnson
University of California,
Los Angeles
Los Angeles, California

Jane Kondev
Brandeis University
Waltham, Massachusetts

David R. Marchant
Boston University
Boston, Massachusetts

Susan K. McConnell
Stanford University
Stanford, California

Anne J. McNeil
University of Michigan
Ann Arbor, Michigan

Jeffrey S. Moore
University of Illinois
at Urbana-Champaign
Urbana, Illinois

Andrew Murray
Harvard University
Cambridge, Massachusetts

Aydogan Ozcan
University of California,
Los Angeles
Los Angeles, California

Muhammad H. Zaman
Boston University
Boston, Massachusetts