CALLING *all* TEACHERS

Everyone agrees that the U.S. needs to train a new generation of inspiring science teachers. *But how?*

by Dan Ferber | *illustration by* Sanna Mander


#1
TEACHER

PART 1 OF 2: THIS ARTICLE FOCUSES ON PRESERVICE TRAINING—TRAINING COLLEGE STUDENTS AND GRADUATES TO BE STEM TEACHERS. PART 2 OF THE SERIES, ON TRAINING TEACHERS ONCE THEY'RE IN THE CLASSROOM—IN-SERVICE TRAINING—IS COMING IN FEBRUARY 2012.

Lauren Miller planned to teach high school biology as well as health and nutrition. She knew that having hands-on research experience would boost her resume. So the 21-year-old secondary education major at Western Michigan University (WMU) signed up to work in a biology laboratory. To be honest, Miller says, she was not looking forward to it.

"I came in thinking research was antisocial and I'd be sitting at a lab table by myself," she says. She expected a long, lonely 10 weeks.

But Miller got caught up in her summer research project, part of the university's HHMI-funded program to give science teachers-in-training, also called preservice teachers, some real-life research experience. Often working alongside her advisor, WMU biologist Chris Pearl, she prepared and stained slices of paraffin-embedded mouse testes to measure levels of a key estrogen-producing enzyme in normal and obese mice. And she learned a lot more.

"I found there's a lot of collaboration. You're going to conferences and talking to people in the lab next door. The people in your lab are very willing to help with anything," Miller says. "Now that I have a glimpse of what research is, I'm eager to show students that it's fun to do."

Innovative teacher-training efforts like Western Michigan's could be one solution to what experts consider a national crisis in science and mathematics education. In a 2009 study by the Organisation for Economic Co-operation and Development, for example, American students ranked 17th of 34 developed and emerging countries in science literacy, and 25th in math literacy. To bring U.S. students up to the top of the pack in science achievement and "enable our students to compete in the 21st century economy," President Barack Obama has called for 100,000 new high-quality STEM (science, technology, engineering, and math) teachers in the coming decade.

Education experts agree. Some schools succeed at teaching science and math, but too many of the nation's science teachers know too little about their subject, about effective teaching methods, or both, says Deb Felix, the senior program officer for HHMI's precollege science education initiatives. To be a great science teacher, she says, "You've got to know science and you've got to know effective teaching methods."

Science and math teaching methods and standards are undergoing a major overhaul to include more "inquiry-based" learning, in which students apply scientific thinking and experimentation to solve actual science problems (see Web extra sidebar, "A 21st Century Cookbook").

Educators are still figuring out how to train teachers to teach science and math this way. There's no one-size-fits-all approach to recruit teachers and get them up to speed on the latest science and pedagogy. So, funders of teacher-training programs—including HHMI, the largest private funder of science education in the nation—are experimenting. The particulars vary, but the goal remains the same: to train and put in place the talented science and math teachers that the nation desperately needs.

To ensure future teachers have the training they require to be comfortable and effective teaching science, HHMI is encouraging undergraduate institutions to focus on ways to promote high-quality science teacher training, says David Asai, director of HHMI's precollege and undergraduate programs. "Just as good pre-med programs provide a framework in which the student can demonstrate the competencies required for success in medicine," he says, "so too should science teacher training engage the undergraduate in intentional professional development."

Luring the Talent

In the midst of a national shortage of qualified science and math teachers, school districts don't always have the luxury of worrying about educational fine points. Sometimes they have slots that need to be filled now. To recruit good science and math teachers, school districts have offered signing bonuses, housing assistance, and tuition reimbursement. Policy makers have forgiven loans

and created initiatives to lure science and math teachers to districts that need them, especially high-need urban and rural school districts, where students are poor, academically struggling, or both, and teachers don't stay long.

A large supplier of STEM teachers nationwide is Teach For America (TFA). Education's version of the Peace Corps, TFA takes recent graduates of elite colleges, puts them through a five-week boot camp on how to teach, and places them in high-need districts for two years. During the 2010–11 school year, TFA's corps included 2,980 middle- and high school STEM teachers. And more than 2,300 of the organization's current corps of 9,300 teachers teach elementary school, which includes at least some science and math instruction, according to an overview of TFA's STEM initiative provided by spokesperson Carrie James.

TFA relies on selectivity to provide good teachers: the 2011 corps of teachers had an average undergraduate GPA of 3.6, and only 2,980 of 16,850 STEM applicants were accepted. But critics argue that their training is too short. Julian Vasquez Heilig of the University of Texas at Austin and Su Jin Jez of California State University, Sacramento, reviewed 11 outside studies on TFA and concluded that TFA teachers taught their students reading and math as well as or better than other uncertified beginning teachers but not as well as fully credentialed beginning teachers. The TFA teachers, like others, got better with experience. But after three years, 80 percent of them had left teaching. That's about twice the attrition rate of conventionally trained teachers, the authors wrote in a 2010 report from the Education and the Public Interest Center at University of Colorado and the Education Policy Research Unit at Arizona State University. To be fair, however, TFA teachers agree to teach for two years, and TFA's own research shows that 61 percent of its corps continues to teach the year after the two-year commitment ends.

Heightened teacher turnover does not serve students, says Francis Eberle, executive director of the National Science Teachers Association. "It generally takes several years for a person to get good at teaching. So students who keep getting new teachers are really disadvantaged."

The Noyce Scholarship Program at the National Science Foundation (NSF) takes a different approach. NSF provides funds for scholarships, stipends, and teacher training at colleges and universities that prepare undergraduate STEM majors and STEM professionals to teach. In exchange for each year of NSF support, Noyce recipients commit to teach two years (and receive a $10,000 salary supplement for each year) in a high-need school—one with high poverty, high teacher turnover, or many teachers teaching outside their field. As of fall 2010, Noyce had produced 4,148 new K–12 science or math teachers.

Noyce scholars have all majored in a STEM discipline and taken upper-level science courses, including laboratory courses, and many have conducted independent research. This gives them "the confidence to teach, the excitement, and the passion for the discipline that you might not find in a teacher who's taken just one or two courses" in their subject, says NSF's Joan Prival, who administers the Noyce program.

A University of Minnesota team surveyed 555 Noyce scholarship recipients from 2002 to 2006 and found that their GPAs were high and the proportion of Noyce scholars who were minorities was higher (33 percent) than the proportion of minorities working as STEM teachers nationwide (up to 14 percent). And 22 percent of Noyce scholars take on a leadership role in their first few years at a school, serving as a department chair, for example, or sitting on a committee that develops a new curriculum.

"Programs like Noyce have done a tremendous job in helping raise the level of the teaching profession in the eyes of undergraduates," says John Keller, a planetary scientist and director of the Center for Excellence in Science and Mathematics Education at California Polytechnic State University in San Luis Obispo.

Other preservice initiatives reach out to students with proven science or mathematics chops and train them to teach. Prospective master's degree students at the HHMI-funded Center for Science and Mathematics Education (CESAME) at Stony Brook University in New York need a bachelor's degree in science with a B+ average. Quite a few are health professionals or scientists—including, in recent years, four dentists, a medical doctor, and a research scientist.

At Stony Brook University, David Bynum trains top-level science students to teach and requires that they spend lots of time observing and teaching in classrooms.

Brian Park

"Right at the beginning, if you attract talent, it makes a lot of the problems go away," says David Bynum, CESAME's director. "The best districts lap up our graduates. That to me is a very powerful indicator of success," he says. And almost a third of CESAME's graduates teach in high-need districts.

Some programs focus on attracting that talent young. UTeach, launched in 1997 at the University of Texas at Austin, offers freshman science majors their first two education courses for free—a significant recruitment tool in this age of rising tuitions. Students also save thousands of dollars by completing their science and education training in four years with a bachelor's degree that qualifies them for certification to teach secondary school science or math in Texas, rather than the usual five or more years to get a bachelor's in science and a master's in teaching. UTeach has graduated 675 teachers, and 82 percent of its graduate hires are still teaching after five years, compared with about 50 percent of all teachers nationally. A nonprofit group called the National Math and Science Initiative is replicating UTeach at 28 universities in 13 states. Altogether about 4,700 more teachers-in-training are enrolled at these sites, according to UTeach. Both the National Research Council and the President's Council of Advisors on Science and Technology, or PCAST, have recommended further expansion.

At the new HHMI-funded program at Pennsylvania State University, molecular cell biologist Richard Cyr and his colleagues bring working teachers and education professors into freshman seminars to talk about teaching as a career and help interested students plan their coursework. They encourage academically successful biology majors to mentor their peers, watching them for traits like leadership, perseverance, and patience that predict a successful teaching career, Cyr says. Promising students are invited to help a graduate teaching assistant instruct a laboratory section of an undergraduate biology class; if they perform well, they are offered jobs as teaching assistants.

Many of the strongest programs, including UTeach, get undergraduates teaching early, which tends to get them hooked. Kristyn Moloney, a master's student at Penn State, says that after running an introductory biology laboratory section as a junior, she knew science teaching was for her. Year-end course evaluations from her students showed her how she had helped them. "That's what set it in stone for me, that this is what makes me happy," she says.

THE CHALLENGE

TOTAL K–12 TEACHERS IN THE U.S.:

3.6 MILLION

TOTAL WHO ARE STEM TEACHERS:

477,000

ESTIMATED STEM TEACHERS WHO LEAVE PROFESSION EACH YEAR:

25,000

TOTAL NEW STEM TEACHERS REQUESTED BY PRESIDENT OBAMA:

100,000 in 10 YEARS

SOURCES:

National Center for Education Statistics (*nces.ed.gov/fastfacts/display.asp?id=28*)

President's Council of Advisors on Science and Technology, September 2010 (*www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-stemed-report.pdf*)

Back to Basics

When students go out to teach, they need up-to-date knowledge of their discipline. So even though the prospective science and math teachers enter the Stony Brook program with at least a bachelor's degree, half of their courses are still in their STEM discipline, be it mathematics, biology, chemistry, physics, or geology, Bynum says. And the science-trained Noyce scholars and UTeach students have the grounding they need to teach STEM classes.

But most science and math teachers still come through education schools, and their knowledge of the discipline they are teaching may be outdated or sketchy, especially in the lower and middle grades. For example, a Department of Education survey in 1999–2000 found that 29 percent of middle-school biology teachers and 41 percent of physical science teachers were not certified to teach their subject and did not major or even minor in it as an undergraduate. Certification requirements have tightened since then in many states, but the problem remains.

Maxine Singer, board president and founder of the Washington, D.C., branch of Math For America, a nonprofit dedicated to improving K–12 math education, recalls leading a training session for in-service elementary teachers at the Carnegie Institution for Science, where she is president emerita. According to Singer, many struggled when converting all but the most basic fractions and decimals. Jeff Nordine, assistant professor of science education at Trinity University, had a similarly disheartening experience meeting with some in-service elementary school teachers. "It was news to them that water expands when it freezes," he says. "I don't remember not knowing that."

Many future elementary school teachers are education majors who have taken a minimum of science during their undergraduate years, Nordine says. "They are uncomfortable with science, they don't like it, and they feel dumb. Then they have to teach it to students." Not surprisingly, the students lose interest in the subject.

At Western Michigan University, Susan Stapleton (right) and colleagues require science teacher trainees to do a 10-week research project. The experience convinced Lauren Miller (left) that research is fun—enthusiasm she'll share with future students.

Learning by Doing

When Nordine teaches elementary science education to future teachers, he tells them, "Listen, it's OK to not know the answer; that's what science is all about." He helps them learn scientific content, as well as where to find journals and other science-teaching resources, from the National Science Teachers Association and elsewhere that can help them on the job.

Even more important, Nordine and other leading science educators also show future teachers how to create inquiry-based science units, in which students learn by solving real-world problems. For example, some preservice teachers in his elementary science education class have created a unit in which kids learn about density and buoyancy by investigating whether heavy objects sink and light objects float.

Such lessons build on two decades of work by cognitive scientists and education researchers on how students learn. In a landmark 1998 study, for example, Barbara White of the University of California, Berkeley, and John Frederiksen, now at the University of Washington, had students at an urban middle school learn physics by doing it—by formulating a question, generating predictions, carrying out and analyzing experiments, and checking the results with scientific models. Compared with grade 11 and 12 physics students who memorized facts and plugged through algebraic formulas, the middle school students learned more physics (averaging 68 percent on a short test of physics comprehension, versus 50 percent for the high school students) and were better at thinking scientifically. Researchers have since honed their understanding of inquiry-based learning by determining which types of classroom exercises promote real inquiry and which don't, says K. Ann Renninger, an HHMI-funded educator and education researcher at Swarthmore College.

Teachers can help students learn science by doing it, if the teachers have done the same. "Folks who want to teach need to know what it means to ask a good scientific question, to design experiments to answer it, and to interpret the results," says Susan Stapleton, a biochemist who helps run the HHMI-funded preservice program at Western Michigan University. WMU is the sixth largest U.S. preservice teacher training school. Most of its students go the traditional route: they major in education, including a slew of pedagogy courses, and minor in their teaching specialty (WMU produced 463 preservice teachers in 2010; 91 were science and math teachers).

That's why she and one of the program's codirectors, science education professor Renee Schwartz, require science teachers-in-training like Lauren Miller to do a 10-week summer research project. But that's just part of the program. "It's one thing to give them research experience. It's another to translate that into teachable units they can take into the classroom," Stapleton says. So she and Schwartz will teach a class for preservice science teachers next spring on how to turn their research experiences into inquiry-based laboratory exercises. The trainees will then teach the exercises they've created to middle school students during a two-week science camp the following summer.

Giving preservice teachers tools like this helps them once they're on the job. Laura Gurick, a 2010 CESAME graduate of Stony Brook University, drew on her training last year for the 10th-grade chemistry class she taught at Herricks High School in New Hyde Park, New York. She could have taught paper chromatography, a method to separate and analyze component chemicals from a mixture, using a conventional laboratory in which the students were told exactly what to do. Instead she drew on a workshop she'd taken at Stony Brook on how to turn a conventional laboratory into one that's inquiry based.

Gurick told her students that there had been a kidnapping, that one of them was the kidnapper, and that a ransom note and a pen had been found at the scene of the crime. Several students

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Lauren Miller: Peter Baker Susan Stapleton: Peter Baker

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(LIVING CHEMISTRY)

can launch career-changing collaborations, as Crabtree and Schreiber have learned.

"The important thing," says van der Donk, "is that biologists and chemists are really talking to one another more than we used to. As a result, biologists understand better what chemists can bring to the table. And chemists understand better the questions that biologists really care about." This, he says, has led to a bigger impact of chemists on biological problems. And they've only just begun. ■

FOR MORE INFORMATION: See other articles on researchers applying chemistry to biological questions throughout this issue, in print, online, and on the iPad.

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were suspects, she added, and each suspect used a characteristic brand of pen. The students figured out how to use paper chromatography to distinguish the inks in Bic, RoseArt, and other pens. Most were able to finger the guilty suspect. "I wanted them to understand the concepts more deeply than they would if they had just been given the instructions," Gurick says.

Getting in Practice

Stony Brook's curriculum, like all good teaching programs, also requires preservice teachers to spend plenty of time in schools, watching and teaching. Before they're allowed to student-teach in the third and final semester of their master's course, preservice teachers at Stony Brook must spend 100 hours each observing teachers—in middle schools and high schools, in ordinary and high-need districts, and teaching different subjects. Many preservice teachers also help teach in the university's unique biotechnology, chemistry, physics, and earth science teaching laboratories. Science teachers from 80 percent of Long Island's school districts bring their students for half-day laboratories.

Establishing strong ties with local schools can pay off for much smaller teacher-training programs. At Trinity University, aspiring science teachers do a year-long internship at one of three "professional development schools"—elementary, middle, or high school—in San Antonio, where they are mentored by an experienced teacher. In exchange, the university appoints these mentors as clinical faculty for a year, complete with library and other privileges, and Trinity faculty lead professional development initiatives for the teachers at each school.

Back in Kalamazoo, Lauren Miller will do her student teaching next spring, and next summer she'll teach eighth graders the unit she develops on sex hormones and obesity. Beyond that, she plans to teach family consumer science, which includes personal nutrition, reproductive health, and parenting, to high schoolers. She'll take her newfound enthusiasm for science with her. "Science is asking questions—you ask one question and you've got 10 more after that," Miller says. "I want to take that to my students and get them excited about science." ■

FOR MORE INFORMATION: To learn about new science and math standards and to see a comparison of preservice programs, visit www.hhmi.org/bulletin/nov2011.

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(HAVE MICROSCOPE, WILL TRAVEL)

Planchon, now an associate professor at Delaware State University, plans to develop similar microscopes to look at live multicellular organisms and continue working closely with biologists. Ultimately, Betzig's group would like to merge the Bessel sheet's capabilities with the super-resolution of PALM, a project that the Galbraiths—frequent collaborators at Janelia Farm who brought their own custom-built PALM with them to Woods Hole this summer—are urging forward.

The long days at MBL will transition into long days back at Janelia Farm, as the Betzig team continues to improve the Bessel sheet. Because what they really learned at Woods Hole, Gao says, is how urgently biologists await those improvements. ■

WEB EXTRA: Hear Eric Betzig talk about the microscope and see how it dazzled Woods Hole students and faculty in an audio slideshow. Go to www.hhmi.org/bulletin/nov2011.

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(STAR SEARCH)

of background information concerning both wild and captive mouse lemurs with new genetic and genomic data is very exciting."

At Stanford, Krasnow and his group are pushing forward with mouse lemur research, starting with seeking out additional samples and setting up collaborations with Malagasy scientists and other lemur biologists around the world. They think that learning about the genetics and physiology of mouse lemurs could help preserve the endangered animals.

"For decades Madagascar has been seen as a hotspot for biodiversity, and rightly so," Richard says. "But it is welcome to see that recognition translating into a broader scientific interest in mouse lemurs—primates found nowhere else in the world." ■

WEB EXTRA: Travel with Mark Krasnow and his team as they explore the rainforests of Madagascar. See the slideshow at www.hhmi.org/bulletin/nov2011.

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