BUILDING A BETTER SCIENCE TEACHER

Experience and degrees don’t matter in the classroom nearly so much as mastery of science and math and some plain old smarts

By Pat Wingert
In a renovated warehouse in a weary-looking section of Troy, N.Y., 25-year-old Katie Bellucci has the rapt attention of 27 fifth graders. They are singing, stamping, clapping and waving their hands in the air—far more excitement than you would expect for ratios and fractions. The class is working together on a word problem involving a fictional basketball team with a win-to-loss ratio of 9:3. What is the ratio of losses to total games played? Bellucci encourages them to reduce it. “Okay, who’s got the GCF?” she asks, referring to the greatest common factor. She zips up and down the aisles, cajoling one student and then another for one more piece of the solution. The students track her every move, knowing she may call on them even if their hands are down. “I’m seeing so many lightbulbs and so much diligence,” she says. If an answer comes easily, she will push ahead with that student and ask for the how and why behind it. The bell rings, and as the kids file out for lunch, each one hands Bellucci an “Exit Ticket”—the solution to two problems that exemplify the core lesson of the day, which Bellucci will scrutinize to determine if the class mastered the day’s objective.

Troy Prep, where Bellucci teaches, is one of the higher-performing public schools in New York State even though the vast majority of its students come from low-income families. In 2011, the second year the school was open, 74 percent of its fifth graders scored at the “proficient” level on the New York State math exam, as compared with only 60 percent of fifth graders across the state. Even more impressive, after two years in the school, 100 percent of Troy Prep’s sixth graders scored in the proficient range. What accounts for the school’s success? Doug Lemov, a leader of the Uncommon Schools Charter Network, of which Troy Prep is a part, does not hesitate: outstanding, well-trained teachers like Bellucci.

In recent years a mounting stack of research has shown that a good teacher is the single most important variable in boosting student achievement in every subject. A good teacher trumps such factors as socioeconomic status, class size, curriculum design and parents’ educational levels. Stanford University’s Eric Hanushek showed that students of highly effective teachers make about three times the academic gains of those with less talented teachers, regardless of the students’ demographics. That is exactly the trouble with math and science education: there are too few teachers like Bellucci. The teacher dropout rate is high, and the education system rewards the teachers it has for the wrong reasons.

The crisis has not gone unnoticed. Not since the Russians launched Sputnik in 1957 have American policy makers, educators and businesses been so focused on improving math and science education. They have been spurred into action by the U.S.’s economic downturn and by growing competitiveness in China, which includes its students’ top scores on international tests. Major players from President Barack Obama on down are describing the U.S.’s lagging performance in science and math education as a dire threat to the country’s future competitiveness. According to results from two Nation’s Report Card tests released earlier this year, only 32 percent of U.S. eighth graders are proficient in science and 36 percent are proficient in math. Meanwhile students from Shanghai earned top scores on the 2010 Program for International Student Assessment test in math and science, whereas Americans placed squarely in the middle of the pack. To

**IN BRIEF**

- America’s economic crisis and China’s growing competitiveness have put new focus on math and science education, including how to improve the way programs train math and science teachers.
- Research shows students of teachers who hold degrees in math and science score higher on math and science tests, yet only a minority of science and math teachers hold degrees in their subjects.
- Teachers with math and science degrees are in high demand, but pilot programs and charter schools are learning better ways of recruiting and retaining highly skilled instructors.
- Educators are also beginning to understand which techniques work best in the classroom, such as hands-on lessons, calling on students unexpectedly, and lessening the fear of errors.
help close the gap, President Obama has proposed infusing our school system with a fresh supply of talent. His prescription: making it a priority to prepare 100,000 highly effective math and science teachers by 2020 and raising learning standards in all 50 states [see “Can the U.S. Get an A in Science?” Science Agenda, on page 12]. “Maintaining our leadership in research and technology is crucial to America’s success,” the president said during last year’s State of the Union address. “But if we want to win the future—if we want innovation to produce jobs in America and not overseas—then we also have to win the race to educate our kids.”

Indeed, at the instigation of the White House, the U.S. seems to be embarking on a national experiment on how to encourage more effective math and science teaching. Increasingly, research is showing that much of what we thought we knew about how to prepare and reward teachers is wrong. According to the conventional wisdom, for instance, Bellucci should not be half as effective as she is. Before coming to Troy Prep, she had no classroom experience, and she never earned a master’s degree in education. What she does have, and what research has shown is even more important, is strong mastery of her subject area: she holds a bachelor’s degree in applied math and crunched numbers at an engineering firm before switching careers.

Yet in most school districts, teachers’ raises and retirement benefits are pegged to experience and postgraduate degrees in education. In fact, classroom time does not predict student achievement as well as many experts have assumed. A new teacher’s proficiency typically grows for a few years but then flattens out. The difference between the achievement scores of students who have a very experienced teacher and one who has been in the classroom for three years, like Bellucci, is small. Graduate degrees do not correlate with higher performance in the classroom, either. Analysts suspect that is because 90 percent of those degrees are master’s degrees in general education rather than in a specific subject area. Conversely, several studies indicate higher math achievement among students whose teachers hold an advanced degree in math.

“AN UTTERLY CHAOTIC SYSTEM”

Legislating change has not been easy. Since 2001 and the passage of former president George W. Bush’s No Child Left Behind, states have been encouraged to hire teachers with degrees in the subjects they teach. As recently as 2008, however, only about 25 percent of science and math teachers at all grade levels held an undergraduate or graduate degree conferred by a math or science department or school. That is partly because of poor teacher retention. Every year 25,000 mathematics and science teachers, out of a corps of 477,000, leave the profession, with nearly two thirds citing job dissatisfaction. To fill vacancies, each state has devised its own rules and regulations for “alternative” and “emergency” hires, some of whom get great training and some of whom do not. Kate Walsh, president of the National Council on Teacher Quality, says, “It is an utterly chaotic system. The best way to summarize American teacher education programs is anything goes.”

In general, teacher certification standards still vary widely from state to state. Some aspiring elementary school teachers, like those in Massachusetts, are required to take rigorous math classes designed for teachers and to score well on tough exams that probe for deep content knowledge. In other states, including Arkansas and Nevada, prospective teachers need only repeat a course they took in high school or one designed primarily to ease
The Value of Bringing Science Home

Yes, great teaching is important. But parents who encourage their kids in science and math are about five times more likely to raise the next Mark Zuckerberg or Mae Jemison by Jon D. Miller

Parents are the essential root of scientific literacy. Those who value science reflect that value in their choice of toys and books, in their use of zoos and museums, and in their own curiosity about the world in which they live. And their knowledge and interests have a profound influence on their children. Recent data from the Longitudinal Study of American Youth, through which my colleagues and I have been following 4,000 Generation Xers since 1987, show that 40 percent of children whose parents actively encouraged them in math and science had major in a STEM (science, technology, engineering, mathematics or medicine) subject in college, as compared with only 8 percent of children who did not receive the same level of encouragement.

Looked at another way, the children of parents who lack an interest in science are at a profound disadvantage. Educational and political leaders should find ways to help all parents—regardless of whether they majored in math or music or went to college—to engage their kids in STEM (opposite page).

They can start by supporting and giving greater prominence to community programs that already do this. The Family Math program that originated at the Lawrence Hall of Science in Berkeley, Calif., has been adopted by museums and community groups throughout the nation and provides an effective way of introducing parents and kids to the math learning process during the elementary and middle school years. Increasingly, these programs, which bring families together to solve hands-on problems, are being offered through schools and have the added advantage of involving parents and teachers in the same process.

Ideally, parents, students and teachers should be involved in cooperative after-school, evening, weekend and summer programs to encourage math and science, and these programs need to continue over the precollege years rather than just a few days or a few weeks. Given the current fiscal crunch gripping public school systems throughout the nation, it is necessary for community and civic groups, churches and unions to foster the initiation and funding of these kinds of programs.

In the 20th century the U.S. did a number of things that produced a strong level of civic scientific literacy among adults. In cross-national studies, I have found that American adults are very competitive in the world in terms of civic scientific literacy: the U.S. ranks second only to Sweden in a comparison of 34 leading industrial nations. America's secret weapon in the 20th century was its commitment to broadening access to college education and its insistence on a set of general education requirements—including a full year of science for most baccalaureate students.

Americans should be proud of these policies and achievements, but one of the unfortunate consequences of our success is that it has masked the dismal performance of our middle schools and high schools in the teaching of science and mathematics. This is a deficit that parents can only partly redress. Schools, families, corporate leaders and policy makers need to work together to improve education. There is no reason that every high school graduate in the U.S. should not be scientifically literate.

their math anxiety rather than increase their mastery of the content, according to the National Council on Teacher Quality.

This type of training pales by comparison with what higher-achieving countries offer. A 2007 study of prospective elementary and middle school mathematics teachers' content knowledge in 16 countries found that future American teachers knew less math than many of their counterparts. Whereas nearly all future middle school teachers in Singapore, Germany, Taiwan and Korea took courses in linear algebra and basic calculus, only about half of U.S. future teachers took those fundamental courses. When it came to algebra knowledge, American teachers scored dead last. One of the reasons for that is there is no agreement about what constitutes a quality teacher preparation program for math or any other subject. "Some [American teacher colleges] are competitive with the best in the world," says William Schmidt of Michigan State University, who directed the U.S. part of the survey. "But some are more like the ones in Botswana. We have that kind of range."

Equally disturbing was the survey's finding that the U.S. teacher preparation programs that ranked lowest in terms of future teachers' math knowledge tended to be at large public universities that produce the largest numbers of teachers. "The bottom quarter of the distribution—the colleges whose students don't know much math—produces more than half of the future middle school teachers of mathematics," Schmidt says. "States need to close those institutions that are doing a really poor job."

ROAD TO REFORM

There are reasons for optimism. Some states are embarking on ambitious reform agendas, helped along by well-respected teacher training programs that are expanding, thanks to an influx of funds from companies and nonprofits. For the past few years the best math teachers in Louisiana, a state in the middle of a major overhaul of its teacher training program, have consistently come from Teach for America, the highly competitive national program that recruits top graduates from the nation's top colleges to make a two-year commitment to teach in hard-to-staff schools. Teach for America's recruits have higher college admission exam scores in math than most teachers, and some data have shown that higher scores correlate with higher effectiveness, says Jeanne Burns, associate commissioner of teacher...
These three factors are determined at birth or early in life and are not influenced by any other variable in the model. Of these, parental educational attainment is the most predictive of a student’s later pursuit of science. Students with higher reading scores in high school were more likely to excel in math.

Steps to Science
The chart at the left, known as a path model, shows how students’ home and school environments interact to predict their likelihood of majoring in science, technology, engineering, math or medicine (STEMM). Highly educated parents are more likely to encourage their children in math and science, which makes kids more likely to do well in math and to take calculus in 12th grade. The completion of high school calculus is one of the single greatest predictors of a STEM major. The model also shows that parents are slightly more likely to encourage boys than girls, whereas teachers are slightly less likely to encourage boys than girls. Surprisingly, scientists and mathematicians are no more likely to raise STEM majors than nonscientists.

The yellow circles mark the variables that best predict a student’s decision to major in science, technology, engineering, math or medicine in college.

Stronger link

Weaker link

Negative link

education initiatives for the Louisiana Board of Regents. Studies of Teach for America in Tennessee and North Carolina schools have shown similarly positive results for science student achievement. Until now, only a third of Teach for America’s members have specialized in science or math, but that is about to change. This past February the organization committed to recruiting 11,000 new math and science teachers by 2015 for the 31 states it serves. The downside is that many of Teach for America’s recruits drop out of teaching after just a few years.

A model program for retaining good teachers is UTeach, an innovative teacher training program that originated at the University of Texas at Austin in the late 1990s. Its goal is to prepare many more science and math teachers with a deep knowledge of their subject. It does so by offering freshmen with math or science majors two free semester-long teaching workshops staffed with mentors. Five years out, 82 percent of its teachers are still in the classroom. UTeach credits those high numbers to the fact that it gives students lots of time in real classrooms right from the start, “so they can decide if they like teaching or not,” says Mary Ann Rankin, former dean of the University of Texas at Austin’s natural sciences department who helped to launch the program. “Some are seduced once they have a really fun experience and see how rewarding it can be.” At the end of four years, recruits graduate with a bachelor’s degree in a field of science or math, plus all the courses needed for teacher certification.

UTeach has won recognition from the National Research Council, among many other groups, and has attracted enough funding from nonprofits and companies to help it expand. In the past three years the number of campuses offering the program has tripled to 30 in 14 states. (Most create their own versions of its witty name: the University of Kansas’s is UKAnTeach.) Meanwhile Rankin, who last year became the president and CEO of the National Math and Science Initiative, has made a commitment to keep the expansion growing. Her goal: 6,000 STEM (science, technology, engineering or mathematics) teachers prepared by UTeach by 2015.

Other teacher training programs have had success by recruiting professionals with strong math and science backgrounds at later stages of their careers. The New Teacher Project (TNTP) focuses on those in their 20s and 30s “who made
What Scientists Say

Scientific American collaborated with Adam Maltese, a science education researcher at Indiana University, on a study aimed at better understanding the experiences of science, math and engineering students and professionals. Based on data from a randomized sample of universities and online volunteers who completed a survey, men and women who pursue STEM degrees tend to become interested in science in elementary school. When asked which people and experiences helped to spark their interest, women were more likely than men to select a teacher, a class at school, solving math problems and spending time outdoors; whereas men were more influenced by tinkering, building and reading. As men and women enter college, passion for the field far outweighs all other influences as the main reason for their persistence.

When did you first become interested in STEM?

- Before elementary school
- Elementary school
- Middle school
- High School
- College
- After college

What type of experience first sparked your interest?

- No specific event (intrinsic)
- Class at school
- Building/tinkering
- Books/magazines
- Math problems/logic games
- Spending time outdoors

Why did you persist?

- Passion for the field
- Good grades
- Influence of family
- Interesting classes
- Influence of teacher
- School club/activity
- Career interest
- Research experience
- Economic necessity

LEARNING FROM “SUPERSTAR” TEACHERS

As educators and researchers learn more about the best ways to attract and train teachers, they are also formulating a better recipe for retaining them. Matthew G. Springer, assistant professor of public policy and education at Vanderbilt University, says pay may not be as clear a motivator as one would think. “There are only a handful of rigorous studies on merit-pay programs,” Springer says, “and the number of different ways you can design them is tremendous. We’ve tested only a few models.” But, he adds, the U.S. Department of Education’s Schools and Staffing Survey has shown that it is about twice as hard to find a good math or science teacher as an elementary school teacher, and “one may conclude that could stem from the fact that there isn’t more market-driven compensation.” What is becoming more clear is the idea that excellent training and job satisfaction go hand in hand. Julia Toews, head of BASIS Tucson, a 700-student charter school that is ranked among the nation’s highest-performing schools in science and math, uses a combination of competitive pay, ongoing development and regular feedback to keep her staff motivated. Her teachers tend to come from the ranks of academe, graduate and postdoctoral students who decided they enjoyed teaching more than conducting research.

Toews is quick to add that holding an advanced degree in science or mathematics does not guarantee anyone a job. “Every teacher [applicant] has to do a teaching demonstration, and for every five I watch, I hire one,” she says. Once applicants are hired, the school provides ongoing teacher development and regular feedback on teachers’ performance and pays higher salaries than the local districts and private schools. With good results, “teachers get a lot of authority and freedom...
and creativity." Toews observes. "We make people want to stay."

Uncommon Schools' Lemov agrees that inadequate training may be behind many teachers' early departures from the profession. "Who doesn't know a lot of people who were teachers who are now Realtors?" he asks. "Without the right training, they are not successful. When someone decides to go into teaching, they know they may not be paid well, but they think they're going to make a difference. If they end up leaving, it's because they're not making a difference. This is actually one of the hardest jobs in the world. We have to give the people who do this work better tools."

What might those tools look like? In other words, what are the specific techniques that, in the words of the White House, "prepare and inspire" students? There is little conclusive research, particularly when it comes to science instruction, write the authors of a 2010 National Research Council report, "Preparing Teachers." Experts agree that students need a mix of factual knowledge, opportunities to practice scientific inquiry and an understanding of "the nature of science," which refers to how scientists gather and make sense of new information. There are better data when it comes to math. Students need to both memorize facts like multiplication tables and think through deep conceptual knowledge before they take on higher-level mathematics. There is also "some evidence" to support the use of cooperative learning and individual assessments to tailor student instruction. But there is more agreement on what should be taught than on the best ways to teach that material.

Efforts to change that are underway. Deborah L. Ball, dean of the school of education at the University of Michigan, has devoted herself for more than a decade to identifying the specific skills that new teachers need before they are ready to take over a classroom. The program she helped to establish, Mathematical Knowledge for Teaching, aims to teach new instructors to diagnose accurately why a student is confused, to maintain a class's attention, and to put together a tool box that includes, for example, a variety of strategies to explain fractions. Her own experience in the classroom, as well as her years as a researcher, Ball says, has convinced her it is "very misguided" to assume good teaching is "intuitive."

Teachers who score high on the Mathematical Knowledge for Teaching skills are more likely to generate student success than those who do well on straight math tests, says Paul Cobb of Vanderbilt, who teaches the strategies to his own students and to experienced teachers looking to improve. Along with his colleague Kara Jackson of McGill University, Cobb has seen dramatically increased levels of student learning by training experienced teachers to use these same techniques. But he acknowledges that the groups were small—12 to 15 at a time—and the effort took more than a year. The challenge now is to figure out how to bring this kind of training to scale. "We know there are exceptional schools," Cobb says. "We're interested in creating exceptional districts."

Lemov, too, has identified 49 techniques that, in his words, "separate great teachers from the merely good." He has spent years observing superstar teachers and zeroing in on the concrete, reproducible traits that make them highly effective. First, Lemov's team focused on how to make reading instruction more effective, and now it is doing the same with math and science, producing teachers like Bellucci. Among the factors the team has noted so far: not letting students off the hook (coming back to a student who at first answered incorrectly to make sure they understand the correct answer) and normalizing error (showing students that getting something wrong before getting it right is normal).

**STRIVING FOR THE TOP**

**STRAINING FOR THE TOP**

**WHILE THE DEBATE CONTINUES**

**OVER THE BEST WAYS TO OVERHAUL THE TRAINING OF MATH AND SCIENCE TEACHERS,** the Obama administration has pledged to continue its effort to boost STEM education from the bully pulpit as well as the treasury. Its Race to the Top program (a national series of competitions that reward states with the most ambitious education reforms with billions in extra federal aid money) has motivated states to overhaul their teacher evaluation programs and made it easier for charters such as Basis and Uncommon Schools to open and for alternatively trained teachers (like those from Teach for America and TNTP) to be hired. The competions have encouraged states to do more to recruit STEM teachers with stronger core mastery and to link student performance to educational school reforms. Stimulus money has also been made available for schools to modernize their science laboratories, and federal money is funding programs such as the Robert Noyce Teacher Scholarship Program, which pays for teacher training for top science and math graduates in university settings. Even so, the administration knows it needs to do much more.

That is one of the reasons government officials are working closely with the nonprofit Carnegie Corporation of New York on what they call the "100Kin10" effort. In the past year they have succeeded in getting more than 100 government, business and nonprofit organizations to join the cause and raise $24 million in their first round of fund-raising from groups that include the Bill & Melinda Gates Foundation, Google and the Michael & Susan Dell Foundation. They are promising donors that investment of this money will be restricted to teacher training programs that have already proved their effectiveness by undergoing vetting by University of Chicago researchers. (So far UTeach and Teach for America are among dozens that have been green-lighted for investment, as have California State University, Arizona State University, Michigan State University, Boston College and the Woodrow Wilson National Fellowship Foundation.)

There is no doubt that the cause is creating heat and light, and its advocates insist that this time around, we will see real progress. "We know this is necessary, and we know this is possible, and it's not happening enough for enough kids," says Talia Milgram-Elliot, who is managing STEM teacher initiatives for Carnegie. "We can do this by activating enough people around the country to make a decision to join us with their own resources, expertise and local knowledge. We can work together to reach this goal."

Although there is still a long way to go, there is no debate over how important this effort is.

**MORE TO EXPLORE**


**SCIENTIFIC AMERICAN ONLINE**

Read more results from Scientific American and Indiana University's survey at ScientificAmerican.com/aug2012/Aa-survey