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EDUCATION WEEK'S

SPOTLIGHT

On STEM in Schools

Editor's Note: "STEM"—short for Science, Technology, Engineering, and Math—is considered crucial subject matter for today's students and critical to their future success in the global economy. This "Spotlight" takes a closer look at innovative approaches to STEM teaching and learning in American schools.

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A School Where STEM is King

A visit to Baltimore Polytechnic Institute creates a strong impression: This is a place for doers.

By Andrew Trotter
Baltimore

Teachers and students at Poly, as it is known here, seem to gather up knowledge and information because they have a use for it. A student is doing background research for her two-year project with local scientists on cannibalism among blue crabs. A group of teenagers searches the Web for a design concept to improve a robot they are entering in a contest. And an aeronautics class discusses the afternoon's weather forecast—as measured from the roof of the school—as a factor in flying several radio-controlled model helicopters.

That focus on applied information is a clue to the bigger purpose at this public school on the northern end of the Baltimore school district: To be a caldron for the blending disciplines known as STEM—science, technology, engineering, and mathematics.

STEM "is blending practice with theory," says Barney J. Wilson, the energetic leader of the school. "Folks talk about STEM as if it were in a box, but it's a way of thinking and living. To really understand it, you have to live it."

For the past two decades, the high school—which for more than a century was organized around manual arts and, later, vocational technology—has remolded itself around STEM.

Robert Marinelli, who arrived 14 years ago and is now the head of Poly's science department, helped convert hand-drafting studios and wood, sheet-metal, hot-metal, and machine shops into computer and design labs, an aviation lab, and other modern learning spaces.

Just as important, he and other teachers developed courses that addressed the T and the E in the STEM acronym, starting with a yearlong course on the fundamentals of engineering that every Poly freshman must pass through.

Today, with STEM education on the lips of national and business leaders and a growing cadre of educators, the 1,350-student school finds itself in a position of leadership.

Admissions Criteria

Poly is one of a handful of selective public high schools in Baltimore, with admission based on criteria favoring students with good grades and recommendations by their middle school teachers and counselors.

"We look for students who have shown aptitude in math and a love for science; also, students who are serious about school" as reflected in good attendance in middle school, Wilson says.

The school has plenty of choices of students. For the 2007-08 school year, 1,800 students from across the city applied for 430 freshman spots.

The current enrollment is 78 percent African-American and evenly split between boys and girls. Nearly all its students are aiming for higher education, Wilson says proudly.

He says the school's three secrets to success are a great faculty, a history of success, and great students.

But Poly has other assets to draw upon, such as the fervent loyalty of its large pool of alumni: The school's database has 20,000 individuals, including members of the city's business, higher education, and government establishment. They provide crucial contacts and give money that supplements the formula funding that the 82,000-student Baltimore district provides each of its high schools.

And some graduates have come home to Poly to teach, bringing lessons from the broader world of industry and academia.

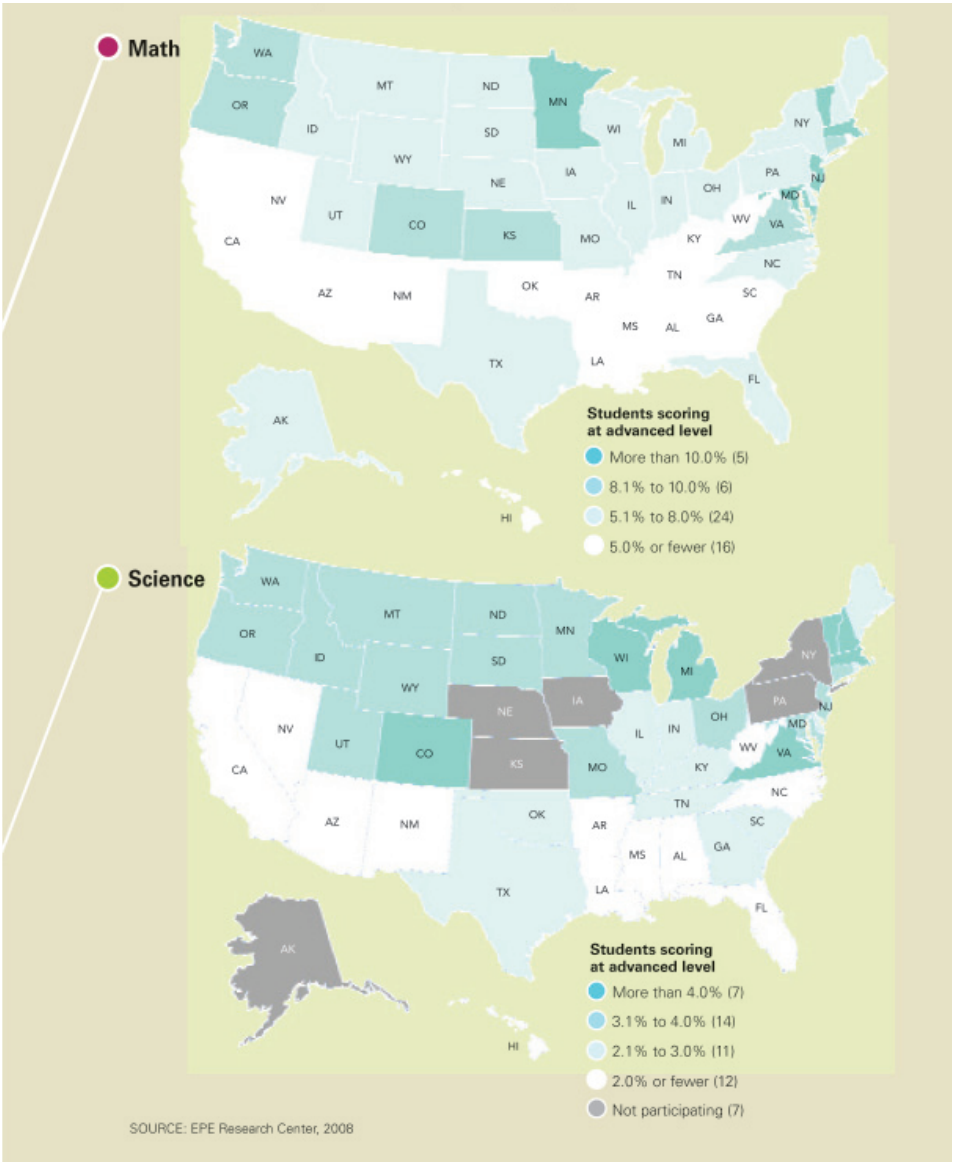
STEM at Poly

Wilson, himself a Poly grad, earned undergraduate degrees in electrical engineering, economics, and math at Carnegie Mellon University before completing a master's degree in industrial administration and a doctorate in urban educational leadership.

From Carnegie Mellon, Wilson

SCORING HIGH IN MATH AND SCIENCE

Nationwide, just 6.6 percent of 8th graders scored at the advanced level on the 2007 National Assessment of Educational Progress in math. Massachusetts led the pack with 14.9 percent of its 8th graders scoring advanced. In science, an average of only 2.9 percent of 8th graders scored at the advanced level nationally on the 2005 NAEP. Massachusetts again ranked No. 1, with 5.8 percent of its 8th graders scoring at the advanced level.



SOURCE: EPE Research Center, 2008

brought a belief in an interdisciplinary approach to creativity and problem-solving that the university calls the "Da Vinci effect." It means that students should have an education that is interdisciplinary, that uses both sides of the brain, that includes a deep understanding of art "almost to the point of being connoisseurs," and that gives them leadership roles, Wilson says.

The school advertises the concept well. A portrait of Leonardo da Vinci, the quintessential Renaissance man, gazes down from a wall in the school's media lab. Students arriving at the sprawling school as freshmen quickly learn what STEM stands for, and the four letters are splashed across a couple of huge bulletin boards in the corridors.

Other banners trumpet the school's latest scores on the Maryland high school science assessment—a 93.4 percent passing rate on the biology assessment: "Let's be the first to 100 percent," it urges—and publicize the Siemens Competition in Math, Science, & Technology and the Intel Science Talent Search, two of the most prominent national contests in the STEM disciplines.

Glass-covered bulletin boards also recount the triumphs of the school's "Research Superstars"—three top-10 national finishers in the Intel contest over the past three school years—just a few steps from a display of interscholastic sports trophies.

The school's commitment to STEM is also built into the curriculum, starting with a course required for all 9th graders, called Foundations of Technology (Fundamentals of Engineering). The course gets students to consider technology as more than iPods or flat-screen TVs; they study the history of technology and explore its relationship to engineering, as well as to science and math.

"Technology is the application, or the fulfillment, of engineering," explains Michael J. Scott, one of the teachers of the course. "Engineering is the application of math and science and technical principles."

Scott, who goes by "Mick," teaches concepts, practice, and application in nine core areas of technology—such as electrical, electronic, structural, and fluid—or as many areas as he can get to before the year runs out.

His spacious classroom is in a former sheet-metal shop, with the conversion still incomplete, where students work on plywood sheets laid across old metal cabinets—but with airy, high ceilings, natural lighting, and an old maple floor.

The nine personal computers at one end of the room are more than eight years old, which requires that they use an old edition of AutoCAD design software; Scott plans to install an Internet connection in the classroom this summer so his students can conveniently use the Web for research rather than having to schedule time in one of the school's computer labs.

But the classroom also has a cluster of band saws and drill presses so students can learn to make working models of technological designs. Scott shows off one model his students designed and constructed—a dialysis machine, made of plywood, plastic tubing, and an assortment of plastic bags. "I was shocked at how well it worked," in separating yellow and red from orange dye, Scott says.

One change of pace that 9th graders enjoy during the technology and engineering course is a two-week stint in Poly's aeronautics lab. Tucked away in a corner of the school is a collection of 14 flight simulators—desktop computers equipped with authentic flight-steering harnesses, foot pedals, and simulation software.

The lab also has a life-size mock-up of the nose assembly of an aircraft and real runway signs donated by a local airport. It is equipped for model rocketry, radio-controlled model planes and helicopters, and access to real-time meteorological data from the weather station on the school roof.

Though the 9th graders get only a taste of the science of flying, students in Poly's Air

Force Junior ROTC program take a full-year flying course, covering the ground training needed to qualify for a pilot's license, says the teacher, Air Force Maj. Roger Gauert.

Getting on Track

Poly gives students chances to explore a wide range of subjects in grades 9 and 10, but by junior year they must select one of two tracks: science or engineering. From that point, the program is highly scripted.

The science track, however, includes the option of a research "practicum," an opportunity to conduct research for up to two years under the mentorship of a professional scientist in the area; students often enter their research projects in high school contests that can give them an edge, and possibly scholarship money, when they apply to colleges.

Both tracks, however, aim to mold students to think scientifically, to put things in perspective, and to solve problems—and to be more than ready for postsecondary studies, Wilson says.

"Our students have a good shot at making a 4.0 in their first year of college," he boasts.

The science track is "pretty much nose to the grindstone," says Lissa R. Rotundo, a science teacher, who teaches courses in genetics and Advanced Placement biology.

Her classroom, a bright, spacious hall next door to Mick Scott's, is another former machine shop that was fully renovated a few years ago with a state grant. It has distinct zones for lecture, reference books, laboratory activities, and Web research on new-looking iMac computers.

But Rotundo, who has taught at Poly for 23 years and wears a beaded necklace shaped like a double-helix strand of DNA, also directs a forensic-science class for 12th graders—an elective class that gives hard-working seniors a respite by requiring no outside homework. But the class is firmly grounded in the STEM philosophy, Rotundo notes, because it pulls together so many disciplines.

"They come in here and say 'Oh, you really can use that,' " she says of students' reactions. "They take the course because they think it's 'CSI,' " Rotundo says, referring to the popular television drama on crime-scene investigation. But as they learn and practice chromatography, fiber analysis, hair analysis, blood-spatter analysis, and DNA fingerprinting, their knowledge and techniques from chemistry and genetics come into play.

The evident success of Poly, an elite school with talented students, raises the issue of whether "cream skimming," especially in an urban environment, benefits the school district and Baltimore's student population as a whole.

To that question, Marinelli, the science department head, responds that if the resources and students assembled at Poly and the other specialty schools were dispersed among all the city's high schools, some families would vote with their feet and move to suburban Baltimore County or enroll their children in private schools if they could afford it.

"We'd lose something really valuable, and we'd never get it back," he says.

Of Poly students who are juniors this year, 100 percent have passed the state's high school science exam, either their first time or after a dose of remediation, according to school officials.

Real-World Experiences

It is important to Marinelli that people realize that Poly students have authentic experiences in science. "They are active scientists, not science students," he declares, of the science practicum. "People think they're washing glassware."

Yet another technology teacher at Poly, Fred Nastvogel, an architect by training, says today's students are less well equipped to handle the real-world, physical aspects of their studies, compared with students a couple of decades ago.

"Many youngsters don't do chores anymore; they don't learn to repair or build things with their hands. Kids have never had the experience of grabbing stuff and making something happen," Nastvogel says. The lack of such experiences, he adds, limits their understanding of how "things go round and round in the universe" and concepts such as how nanoparticles work.

Essential to what he calls the "primitive STEM experience" that high schools should offer, he says, is giving students plenty of experience working with modeling and materials.

Poly is in the midst of planning an engineering-research practicum that will resemble the science-research practicum, Marinelli says. It would provide coursework in advanced engineering for 11th and 12th graders, plus field experiences with professional engineers.

Such a program would likely spur more student projects in engineering, such as an invention by Poly senior Michelle Jones that is meant to help prevent drivers from falling asleep at the wheel. She has designed a dashboard-mounted video camera that monitors a driver's eyes and triggers an alarm if the blink-rate slows or speeds up significantly.

Innovation, of course, is meant to be one of the main fruits of a rich STEM curriculum, yet that term is not well understood, and often confused with invention, teachers at Poly say.

"Bill Gates invented, but that is a rarity," Marinelli says of the Microsoft co-founder, who developed the world's most widely used computer operating software and office software suite. "Certainly, I'm telling students that most of the technology you are going to use in your lifetime has already been invented. You are going to make it better—you are efficiency experts."

Whatever the label given to the product of focused creativity in STEM, school leaders say Poly students are so well prepared that their success after school is virtually assured. "I could grab any three students here and start a business—and in 10 years we'd be a Fortune 500," Director Wilson says.

Program Aims to Build 'Ingenuity'

It can be a tall order for many schools to help students excel in stem subjects. But the Baltimore district has gotten a hand from a foundation-led initiative aimed at doing just that.

The $1 million-per-year Ingenuity Project, begun in 1992 and led by the locally based Abell Foundation, supports about 500 selected students in grades 6-12 at two middle schools and a high school. Goals include succeeding on Advanced Placement tests and excelling in elite national competitions in mathematics, science, engineering, technology, and related fields.

Students apply to take part in middle school; all must reapply for 9th grade. Students are grouped together for science and math, but are blended into regular classes for other subjects.

At Baltimore Polytechnic Institute, a stem-focused high school that draws students from across the city, Ingenuity students in grades 9-12 take part in independent research projects in science lasting two or three school years, including work in the summers.

"They can dig into something, learning things not in a textbook but on the cutting edge," says Dolores Costello, the executive director of the Ingenuity Project.

David Nelson, the research director at Poly, whose position is funded by the project, helps students find their research topics and Baltimore-area scientists to mentor them at an outside facility.

"We try to give students as much autonomy and responsibility to make their own decision to define their own interests," Nelson says. "It is valuable for the student to go through that process."

—Andrew Trotter

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'Green' Classes Flourish in Schools

By Sean Cavanagh

Solar-powered cars have barely begun to inch out of test laboratories onto the difficult road to commercial viability.

But miniature versions of that technology are already being churned out at Whitmore Lake High School.

Students at the Michigan school have designed shoebox-size cars, made of foam board, toothpicks, and solar panels, as part of a new class called Green Tech. It's just one of the many courses focused on renewable and alternative energy that are taking hold across the country as educators seek to channel students' concerns about the environment and conservation into classroom lessons.

Some schools are creating elective science courses on alternative energy, or expanding lessons on that topic within existing science courses. Others have launched applied-science or career-oriented classes, or those that focus mostly on technology, as is the case at Whitmore Lake, located in a 1,200-student district a half-hour west of Detroit.

The Green Tech class has drawn some of the school's top students, as well as struggling learners, said Jen Taylor, who teaches the class. Some teenagers are intrigued by renewable technology; others are convinced it will become more important to society, and employers, in the years ahead.

"It's really exciting to students, even those I never would have thought would be into it," Ms. Taylor said. For some, "it's a realization that this [area] is where there's going to be a job," she said. "I hope I'm preparing some of them for a line of work."

Jake Kerrigan, 16, said he was drawn in because of his overall interest in science and a curiosity about alternative power. He signed up for the elective around the time that gas prices in Michigan had soared to well over $3 a gallon. He has heard leaders in his state—the iconic heart of the United States' struggling auto industry—talk about the need to invest in alternative energy. He believes them.

Green Tech offered the chance to look at "the direction we're heading in the world," the junior said, "and how we're going to transition from our wasteful way of life."

Sun, Wind, and T. Boone

The Green Tech class introduces students to the mechanics and economics of renewable technologies, including solar, wind, geothermal, and hydrogen fuel-cells. Hands-on activities are an integral part of those lessons. Mr. Kerrigan's favorite task was the construction of models of solar-powered cars. That assignment ended with an all-class race in the school parking lot.

Working in groups, Mr. Kerrigan and his classmates spent four periods working on the car, which was about 9 inches long and 7 inches high. They used materials such as cardboard and straw, and small wheels, axles, and gears. Mr. Kerrigan and his team mounted a small solar panel on their car's roof, experimenting with its angle so it would capture maximum light—a design issue they had studied in class. They used real solar panels that the school purchased from Solar World, a Colorado-based company.

Students in Green Tech also study carbon dioxide emissions and each technology's potential to reduce greenhouse gases that contribute to climate change. They've examined energy proposals such as the "Pickens Plan," oil magnate T. Boone Pickens' proposal to expand greatly U.S. wind-power production and the use of natural gas to wean the country off foreign oil.

Whitmore Lake's students are absorbing energy lessons in other ways, too. Their school has received recognition from the U.S. Green Building Council for its environmentally sound features, which include a geothermal heating system with 47 miles of underground tubing. Ms. Taylor talks about the school's efficient features in her classes. Other teachers around the country, some of whom work in solar-powered schools, do the same.

Ms. Taylor created her class with help from Creative Learning Systems, a Longmont, Colo.-based company that helps schools design lessons. The company emphasizes hands-on activities and the in-class integration of science, technology, engineering, and math, or STEM, topics. Creative Learning Systems piloted lesson plans at Whitmore Lake that it hopes to market to other schools, said Matt Dickstein, its chief executive officer.

In Search of Curriculum

Like many educators, however, Ms. Taylor has also been forced to track down many renewable-energy resources on her own, mostly because no single set of materials meets her needs. She has drawn from a number of Web sites, including that of the National Energy Education Development Project. That organization, located in Manassas, Va., devises curriculum on energy issues and supports teaching of those topics.

One likely reason teachers are searching for classroom resources on renewable energy is that the topic has not yet made it into many state academic standards, said Jo Ellen Roseman of the American Association for the Advancement of Science, in Washington.

State standards, which guide teaching and tests, tend to set expectations for students to learn basic principles of energy. But guidelines about conservation and renewable energy are much less common, she said. Ms. Roseman helped write science standards at the AAAS that have served as models for many states. She now directs the AAAS' Project 2061, an effort to improve science education and literacy.

In districts and schools where renewable-energy courses have taken hold, their popularity can be attributed not only to public concerns about climate change and the environment, but to a conviction that the number of "clean energy" jobs will increase, said Karen Heys, the senior director of education at the National Environmental Education Foundation, a Washington organization that promotes environmental awareness in schools and society.

"It's one of the few growth industries right now," Ms. Heys said.

As evidence, she pointed to a 2008 survey of 1,300 employers conducted by her organization. Sixty-five percent of respondents said they valued job applicants' knowledge about "environment and sustainability," and 78 percent said they believe it will increase as a hiring factor in the future.

Her organization has seen the number of visitors to its Web site seeking energy-related curricular materials rise sharply. In addition, when the organization made energy issues the theme of its annual National Environmental Education Week in 2007, it saw the number of its "partner" organizations—schools and other groups that agree to help promote environmental awareness—spike to more than 1,400, from 330 the previous year, Ms. Heys said.

Political Winds?

Despite rising interest in "green" curriculum, it is not unusual for teachers covering

energy topics to draw criticism from students and parents who accuse them of promoting an environmentally oriented political agenda.

Ms. Taylor has heard those objections. When she first began teaching Green Tech, she heard students refer to it as "the hippie class" or the "tree-hugger class." One of her students, she said, was adamant that global warming was a hoax, despite strong scientific evidence that it is occurring and that humans are contributing to it.

She says she tries to address those concerns by focusing on the science and the broader financial and economic realities of alternative energy. Renewable technologies, for example, are more expensive than fossil fuels in many applications despite renewables' environmental benefits.

That teaching strategy makes sense, said Ms. Roseman of the AAAS. Renewable-energy technology may be "on the edge of science," in the sense that it is changing quickly, she said. But educators still can have engaging and scientifically accurate discussions of those technologies, their benefits, and limitations, she said.

"Acknowledge what scientists know, and what they don't know," Ms. Roseman advises teachers.

The chance to study fast-emerging technologies—and the opportunity to try building one of them from scratch—was an easy sell to Jake Kerrigan at Whitmore Lake High School.

His team's construction of a solar-powered car brought thrills and frustrations. While some of their classmates constructed box-shaped vehicles, Mr. Kerrigan's team set out to build a relatively sleek model, with an "I" shape, which would operate on rear-wheel power.

"Lighter, longer, skinnier," was how he described it.

One absolute necessity was to make sure the wheels were straight, for efficiency's sake. They also had to overcome a major engineering glitch with the wiring. If it was too far from the solar panel to the wheels, they discovered, the car wouldn't have enough power.

Until the day of the race, the car wasn't working. But with a few final adjustments, it took off, powering forward at "about a jogging pace," said Mr. Kerrigan. That was fast enough to claim first place.

"Everything just came together," its co-creator said.

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Informal Experiences Can Go a Long Way in Teaching Science

NRC Study Points to Benefits From TV and Games

By Sean Cavanagh

Young people today are exposed to science in ways that were hardly imagined a generation ago.

From their home computers, students can simulate journeys through the human bloodstream and combat diseases that threaten to cover on-screen graphics with "rashes" and interrupt their electronic messages with "sneezes."

On TV, students see detailed breakdowns of forensics and ballistics on shows like "CSI" and numerous spinoffs, which portray police work as both scientifically sophisticated and cool.

Those resources are just two examples of the array of informal science media that have become increasingly accessible in recent years. A new study finds solid evidence that some of those tools, particularly educational television, can boost students' scientific knowledge. Even popular entertainment can stoke their passion for the subject and help them envision themselves as scientists—a serious leap for some students.

Many teachers are attempting to use "informal science" from wider culture as a way of introducing or reinforcing lessons in biology, physics, and other subjects.

Physics Lessons

Their reasoning is obvious, said Steve Carbone, a physics teacher at Forest Park High School in Woodbridge, Va. Today's students work and communicate across media, with e-mail, text messages, cellphones, video, and other means. Movies, television, and Web-based games offer a way to inspire those tech-savvy students, said Mr. Carbone, who uses clips from TV and films in his physics classes.

Mr. Carbone looks for catchy segments to craft physics problems for his students—in some cases, challenging them to show him where programs and films get the science wrong.

"I tell them at the beginning of the year that I'm going to ruin movies for them," he said. "They'll be sitting there in the theater and they'll say, 'That's not possible.'?"

During one recent class, the Virginia teacher used a segment from the TV medical series "House." The episode focused on a drag race, and the lead doctor's task to examine an individual who experienced strange medical symptoms during the high-speed event. In this case, the science presented was largely on the money, Mr. Carbone said. He asked the students to use the information given on the show to calculate the car's rate of acceleration and other factors.

The study of informal science education, released this month by the congressionally chartered National Research Council, found that despite the use of popular TV shows and films in classrooms, limited research is available on their overall effectiveness in improving science learning.

The 'CSI' Effect

Even so, those shows have considerable power to influence, and in some cases distort the public's understanding of science, the study notes.

On the one hand, the authors point out that "Crime Scene Investigation," as "CSI" is officially known, is believed to have resulted in increasing calls from jurors in court cases for physical evidence and advanced technology. Yet there are also examples of cases being dismissed because jurors cited the lack of DNA and other physical evidence that appears on such shows, according to the report.

Despite occasional misconceptions, the authors say, "CSI" has "led to positive outcomes

> "Games are very effective as a way of teaching you how to solve a problem."
>
> HENRY JENKINS
> Co-Director
> Comparative Media Studies Program

in terms of viewers' awareness and interest" in forensics.

The National Research Council study found the strongest evidence that educational TV, through such shows as "Bill Nye the Science Guy" and "3-2-1 Contact," can positively influence children's knowledge of science. In one study cited in the report, children who watched Mr. Nye's show were able to provide more complete and complex explanations of scientific concepts and could better generate scientific ideas.

Substantially less evidence exists on the effect of other media, including digital media, gaming, and radio, on science learning, partly because some of those are new or have not been adequately studied, the authors found.

The clearest benefit of those media, in terms of promoting science knowledge, comes in their ability to motivate students and boost their interest in science, said Bruce V. Lewenstein, who co-chaired the NRC committee that produced the report. Generating that spark of interest should not be underestimated, because it is essential to moving on to acquire scientific knowledge, said Mr. Lewenstein, a professor of science communication at Cornell University in Ithaca, N.Y.

'Tapestry' of Knowledge

Motivation is "a necessary step for learning to take place," Mr. Lewenstein explained. If students "are curious about the world, they can go out and learn about it."

One challenge in studying informal science education is determining which experiences, exactly, have improved students' learning and engagement, Mr. Lewenstein said. As an example, the Cornell professor cited the experience of his college-age son, in an anecdote included in the NRC study.

When his son was young, he was fascinated with elephants. He collected them as stuffed animals. His father took him to zoos and other science centers to see them. When the boy was a bit older, he attended a college lecture on elephants.

Over time, that interest faded. But when his son grew into a teenager, Mr. Lewenstein, on a lark, bought him a calendar with pictures of elephants. His son began reading about elephants again, online. He volunteered in the lab run by the college researcher he once heard speak. Mr. Lewenstein says his son had generally been more keen on politics and the arts than biology. But as the young man neared college age, he looked for schools where he could study not only international relations, but also conservation issues.

Which of those informal science encounters influenced his son's decision?

"We'll never know," Mr. Lewenstein said. And that's the point: Informal science experiences are generally a "tapestry or fabric" of experiences, he said, which, when woven together, increase students' curiosity and understanding of the natural world.

Many students today are cultivating that inquisitiveness through online and video games. Americans spent $10.5 billion on game software and accessories in 2005, the NRC study reports. Some of the most popular games create "virtual" worlds, or three-dimensional environments that change as the participant moves through them, and ask the player to make choices and respond to situations.

Online and interactive games that are closely linked to instruction are sometimes referred to as "serious games." One game cited in the study is Immune Attack, developed by the Federation of American Scientists, a nonpartisan Washington organization focused on science and technology issues.

On-Screen Hypotheses

The game asks players to navigate the bloodstream of a girl born without an immune system. Players look for bacterial infections and "activate" immune cells to go to work. Immune Attack is intended primarily for high school biology students, as a supplementary teaching tool.

After learning of the game through a Google search, Netia Elam used it in her Advanced Placement biology classes at Forest Park High School. Even with teenagers who are accustomed to games with impressive visual displays and features, Immune Attack won them over, partly because they felt challenged by it, said Ms. Elam, now the instructional technology resource teacher at Bull Run Middle School, in the same school system as Forest Park, the 73,000-student Prince William County, Va., district.

Ms. Elam sprinkled the game into lessons on immunology. She found it appealing for a number of reasons: It motivated students to learn more about the topic, and there was no cost to using the game, which can be viewed at the Federation of American Scientists' Web site, at http://fas.org/immuneattack/home.

"There are great resources, and there are amazing labs out there," Ms. Elam said, "but it's difficult to find things that are available for free."

Considerable research exists to support the idea that games motivate students in science and other subjects, said Henry Jenkins, the co-director of the Comparative Media Studies program at the Massachusetts Institute of Technology, who has written extensively on the use and influence of games.

While the most science-effective games may be "fun," what's more important is that they are "engaging," meaning they require hard work, concentration, and persistence, at the same time they're enjoyable, Mr. Jenkins said.

"They can be frustrating," Mr. Jenkins said, "but you're not quitting."

Many of the best games, in fact, ask users to follow a process that could be described as scientific, he added. Complex games often begin by telling students "here's a world—it's unknown," Mr. Jenkins said. Then they call for students to test hypotheses and follow processes for overcoming challenges in that world. That sort of ongoing problem-solving is more difficult to present to viewers of science-based TV programs, he argued.

"Games are very effective as a way of teaching you how to solve a problem," Mr. Jenkins said. "It's a habit of mind that games are good at communicating, rather than simply relaying information."

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FOCUS ON: SCIENCE & MATHEMATICS

Playing Games in Classroom Helping Pupils Grasp Math

Benefits for poor children seen to be particularly encouraging

By Sean Cavanagh

Few family rituals have as fixed a place in the American household, and in the popular imagination, as board games, those impromptu or regularly scheduled contests played by parents and children on kitchen tables and living room floors.

Now, a growing body of research is revealing the potential benefits of using board games in the classroom to strengthen the mathematics skills of children, particularly those from disadvantaged backgrounds.

A new study offers one of the most detailed explorations of that topic yet. Published by a pair of scholars, it concludes that exposing youngsters from low-income backgrounds to a simple board game that involves counting produced large and lasting gains in their understanding of numbers.

The researchers, Robert S. Siegler and Geetha B. Ramani, designed an activity resembling the popular board game Chutes and Ladders, in which they had 124 pupils count and move pieces along numbered squares. All the preschoolers tested were from families that participated in the federal Head Start program, which serves children from impoverished backgrounds.

Students played that board game four times, for 15 to 20 minutes per sitting, over a two-week period. At the end of the study, their knowledge of math in four different areas of number sense had increased greatly, the researchers found. The experiment has shown the same results among other young students they've tested.

Those results, and related research, offer an unconventional strategy for developing crucial math skills among young, disadvantaged students, including minority children, scholars say. As it now stands, those pupils' performance in math traditionally lags behind that of their better-off and white peers.

Many children from poor families have limited exposure to board games and simple math-related activities at home. Spending even a small amount of time on fun, basic board games could spark an early interest in math and produce an academic payoff later, some researchers say.

"Young people learn a great deal about the world through play, and games are one source of play," said Mr. Siegler, a professor of cognitive psychology at Carnegie Mellon University in Pittsburgh. And when it comes to learning math, he added, "the games that build understanding of numerical magnitudes are crucial."

A Great Race

Researchers have been exploring the benefits of board games and other informal entries into math for decades. But while scholars have broadly examined the effect of strategies that blend games with other activities, such as songs and computer programs, Mr. Siegler and Ms. Ramani, an assistant professor of human development at the University of Maryland, sought to quantify the effect of board games in particular.

In their study, published in the March-April issue of the journal Child Development, they created a board game called The Great Race. The children, all from the Pittsburgh area, took turns using a spinner, then moving miniature figures—a bear or a rabbit—one or two paces along a board marked with 10 steps.

Those who played that basic game showed significant gains in four different measures of their number sense, based on tests designed by the two researchers. Those gains remained just as strong when the preschoolers were tested nine weeks later, after their last game-playing session. By contrast, the children who played a game that asked them to move along colored spaces, rather than numbered ones, did not improve on any of those numerical measures.

Students from relatively privileged backgrounds tend to be exposed to math at home not only through simple family games and

> "Young people learn a great deal about the world through play, and games are one source of play."
>
> –ROBERT S. SIEGLER Professor, Carnegie Mellon University in Pittsburgh.

activities, but also through parents' subtle use of math-related language, said Sharon A. Griffin, a professor of education at Clark University in Worcester, Mass., who has studied board games.

"The quantitative world is [presented] through language—bigger, smaller, taller, shorter," Ms. Griffin said. "There's explicit talk, using numbers, that doesn't seem to happen in lower-income homes" as often, she said.

In the late 1980s, Ms. Griffin developed Number Worlds, a program that uses specially designed board and card games and other activities to promote math understanding among struggling pupils in early grades. Today, the program is sold commercially through SRA/McGraw-Hill.

She sees a growing focus among educators and researchers nowadays on board games. One "powerful boost" in that interest, Ms. Griffin believes, has come from emerging neuroscience research on how numbers are represented in the brain, and what that means for students learning math.

Ann McPartland, a teacher at Jacob Hiatt Magnet School in the 23,000-student Worcester district, has noticed that the basic counting ability of her prekindergartners varies greatly, and she sees a link to their families' economic circumstances.

For Practice, and Play

The teacher began using board games, card games, and other simple counting activities designed by Number Worlds about seven years ago, in an attempt to close those gaps. One of her favorite counting games is not played on a board, but rather on a vinyl sheet with numbered spaces that she spreads out across her classroom floor.

Her students stand in the spaces, numbered one through 10. She has them walk forward while counting aloud, then backward, counting in reverse order. When a student stands on a particular space, the teacher will ask the class how many steps he or she must take to reach a different number.

"I'm hoping they can reach the point where they understand that six spaces, plus four, equals 10," explained Ms. McPartland, who's been teaching for 25 years. A large percentage of her pupils, she estimates, come from impoverished backgrounds.

Games "are relevant to children," she said. "It's something tangible for children. They can see and touch [them]."

Many commercial publishers of math materials use board games and card games, involving dice and other materials, in their curricula. Everyday Mathematics, taught to an estimated 3 million elementary students in 185,000 classrooms nationwide, incorporates board and other games into its print materials and computer-based programs.

Games offer math teachers a way of practicing and reinforcing arithmetic and other math skills, as well as supplementing a sole diet of drills and practice-problems, said Andy Isaacs, the director of the third edition of Everyday Mathematics. Not only do games engage students, they also present the opportunity to present "high level" math concepts in a colorful and simple way, said Mr. Isaacs, who is also a senior research associate in the physical sciences division at the University of Chicago.

Despite those benefits, some teachers and parents are reluctant to use board games and similar activities, he noted. Those critics tend to regard them as activities that cut into time spent on practicing problems, when in fact games should be used as another form of math practice.

"The idea that something could be simultaneously fun and worthwhile academically just doesn't add up for them," Mr. Isaacs said of the skeptics.

Research on the link between board games and math learning has implications not just for educators, but also for parents, said Douglas H. Clements, a professor of learning and instruction at the State University of New York at Buffalo.

Turning off the television and engaging children in a simple game just a few times a week can greatly improve their comfort in math, said Mr. Clements, who has designed a curriculum based in board games, puzzles, computer software, and other activities to build youngsters' number skills.

He said he doesn't doubt the educational value of some television programs and online activities, but emphasizes the value of other, simple options.

"There's a huge amount of math in these board games and card games that is not on television and video games," Mr. Clements said. "Even if you played once or twice a week, it would probably have a real effect on kids."

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Catching Up on Algebra

More schools are using unconventional textbooks and other curriculum materials to help make struggling middle schoolers 'algebra-ready.'

By Sean Cavanagh
Camarillo, Calif.

A popular humorist and avowed mathphobe once declared that in real life, there's no such thing as algebra.

Kathie Wilson knows better.

Most of the students in her 8th grade class will be thrust into algebra, the definitive course that heralds the beginning of high school mathematics, next school year. The problem: Many of them are about three years below grade level. Ms. Wilson's job is to help them catch up—and quickly.

Every year, scores of middle and high school math teachers face the same challenge as Ms. Wilson, who is in her eighth year of teaching here at Monte Vista Middle School, tucked into the exurbs about an hour north of Los Angeles.

The push to ensure that all students, not just the academically gifted, take introductory algebra and do so earlier has gained widespread acceptance in U.S. schools over the quarter-century since A Nation at Risk advocated strengthening graduation requirements in math. That movement has been driven in recent years by rising state and local high school standards, which in turn have forced higher expectations for courses taught in middle schools. One result of those efforts is that beginning algebra is being taught earlier, typically in the 8th rather than the 9th grade.

Now, after years of raising the standards, some policymakers are moving to help thousands of middle and early high school algebra students who cannot keep up.

Last year, for the first time, California state officials approved an entire set of math programs devoted specifically to "algebra readiness," or raising the skills of students likely to struggle in that subject. Similar algebra-readiness materials are being used in other states and districts around the country.

The strategy Ms. Wilson is trying in her classroom is simple yet ambitious.

She uses a program aimed at rebuilding students' foundational math skills, normally taught from 2nd through 7th grade, over the course of a single academic year, while introducing the students to basic algebraic principles and language.

Created by the MIND Research Institute, a nonprofit organization based in Southern California, the program relies heavily on visual explanations of math in textbooks and computer software. The approach is meant to engage and motivate students, and build a bridge between elementary math and algebra.

It is also designed to help students of different ability levels, such as those in Ms. Wilson's class who have shaky English-language skills. The program's visual model helps students connect different math concepts and remember them, its developers say.

"The way I was taught growing up, you just memorize the algorithms and you'll learn the math," Ms. Wilson said during a break from her class one day this semester. "This [new approach] is taking the math and showing them why it works, and building it up for them."

Setting the Bar

Along with California, a number of other states have crafted programs aimed at girding struggling students for introductory algebra. Virginia oversees a statewide algebra-readiness program for students in grades 6-9; roughly 60,000 tests are given each year to determine whether students need extra help. Kentucky is supporting an algebra-readiness pilot program in several districts. Many school systems nationwide, of all sizes, have launched their own efforts.

Interest in such programs has coincided with the nationwide drive to teach algebra earlier.

From 1996 to 2005, the proportion of U.S. students who reported taking Algebra 1 as 8th graders climbed from 24 percent to 34 percent, though the share varies enormously by state, according to the Council of Chief State School Officers. California raised the algebra bar considerably in 1997, when it adopted standards that encouraged all students to take Algebra 1 in 8th grade. The state later required all students to complete Algebra 1 to graduate with a regular high school diploma.

By some measures, those steps appear to be having the desired effect. The percentage of California 8th graders taking Algebra 1 has risen with the tougher standards, according to testing data, and the proportion of students who have not enrolled in that course by junior year has declined, an independent report showed.

Yet many California students are still falling short.

Just 23 percent of the 740,000 middle and high school students who took the state's end-of-course Algebra 1 exam reached proficiency in 2007, roughly the same proportion as four years earlier. By contrast, 40 percent scored "proficient" or better on the state's test of 7th grade math.

In an attempt to help those students, the California state board of education last year adopted 11 separate algebra-readiness programs. That action enables districts to use state money to buy those textbooks and classroom materials. The programs target 8th graders, but districts can use the programs in other grades, too.

Those resources have been welcome in the 16,500-student Oxnard Union High School District, which accepts students from Monte Vista and several other feeder middle schools. The district is piloting two of the new algebra-readiness programs, including the one developed by the MIND Institute, for use in 9th grade.

The needs in the Oxnard Union district are clear. Roughly 40 percent of its freshmen arrive unprepared for Algebra 1 or higher math, according to Jim Short, the district's math specialist.

"Giving the same old material to students—it hasn't worked for eight years. I don't see why it would work the ninth time around,

either," Mr. Short said. Too much math teaching today, he argues, pushes students through "the same standards repeatedly, without really getting at the underlying foundations."

Of the algebra-readiness strategies, he said: "I definitely believe [they] will help."

Numbers to Symbols

Completing introductory algebra, and doing so relatively early, benefits students later on, research suggests. A 2005 federal study found that more than 80 percent of students who took Algebra 1 as 9th graders went on to complete Algebra 2 or an advanced math class, such as calculus, during high school. Only 29 percent who did not follow that schedule ended up finishing upper-level algebra or calculus.

Still, algebra has long represented as much a psychological hurdle for students as an educational one.

Most of the math that students encounter in elementary school is relatively concrete: whole numbers, fractions, one- or two-step procedures, problems like 7 x 8 = 56.

Algebra, for many students, is a departure from the concrete. In the simplest terms, it's the study of relationships between numbers, with some numbers represented as symbols. It deals with equations, functions, and polynomials, and problems like 2x + 3y = 56, when x = 6.

Many students struggle with those kinds of problems, or fail to see the point of them (as did the comic essayist Fran Lebowitz, the author of the putdown about algebra having no connection to real life).

"Algebra is a pretty big leap in abstraction," said Jon R. Star, an educational psychologist at Harvard University who has studied how students understand math.

For many students, Mr. Star said, "ideas about x and y just don't make sense." U.S. schools, he said, have struggled to "help students make that leap."

The goal of having more students—ideally, all of them—take Algebra 1 in 8th grade dates at least as far back as the 1960s, and the idea gained popularity over the following two decades, math scholars say.

One factor was the belief that many middle schoolers were not being challenged by math lessons that were redundant and too focused on arithmetic. But probably the biggest influence was the view that American schools were arbitrarily denying academic and economic opportunity to entire groups of students, by giving some the chance to take 8th grade algebra and relegating others to more basic math.

It became "an equity issue," said Jeremy Kilpatrick, a professor of mathematics education at the University of Georgia, who has examined the history of algebra teaching in U.S. schools. Without algebra, "not only were your chances of getting into college reduced, but your chances for majoring in certain subjects were reduced," he said. "Algebra was the ticket."

At the same time, policymakers were calling for higher standards. A Nation at Risk, the influential federal report released in April 1983, lamented that relatively few American students reached advanced algebra. It called for students to complete a minimum of three years of high school math and identified "algebraic concepts" as core content.

Not surprisingly, the public tends to see algebra as important mostly because schools, colleges, and test developers see it as important, said Zalman Usiskin, the director of the University of Chicago School Mathematics Project and a prominent researcher and textbook author.

But contrary to popular opinion, algebra has great value in everyday life, Mr. Usiskin said.

Algebra helps people solve problems that require them to consider several quantities that depend on each other, he explained. Calculating the payment on a car or a house using different interest rates can be simpler with algebra, as is figuring out how health is affected by factors such as diet, body weight, and age, Mr. Usiskin wrote in a 1995 essay on algebra's importance.

"You can live without it, but you will not appreciate as much of what is going on around you," Mr. Usiskin reasoned in that article. "You will be more likely to make unwise decisions, and you will find yourself with less control over your life than others who have this knowledge."

Coming up with strategies to prepare students better for algebra has been a major focus of policy experts in recent years. The National Mathematics Advisory Panel, a White House-commissioned group, released a report last month that calls for a more logical progression through foundational math, particularly in whole numbers, fractions, and geometry and measurement, as a primer for algebra. *(See Education Week, March 19, 2008.)*

Review and Rebuild

This school year, Monte Vista Middle School's Ms. Wilson has returned to the foundations of math continually. When introducing her 8th graders to a topic such as fractions, she often begins with material typically found in a relatively early grade, then gradually moves into more complex problems, blending in algebraic concepts along the way.

The idea is to give students both a refresher on the basics and a taste of the language and thinking required in algebra, according to the MIND Institute, the group that developed the program.

In a class one day this semester, Ms. Wilson sought to bridge the divide between basic arithmetic and algebra during a lesson on prime factorization. She writes out 24/18 on the board, then asks students to factor out the fraction using prime numbers—

A View From Abroad: Algebra Comes Early

While more American students are being encouraged to take introductory algebra in 8th grade, their foreign peers are typically exposed to that math content by at least that grade level, if not earlier, a well-known scholar has found.

Research conducted by William H. Schmidt, a professor of education at Michigan State University in East Lansing, has shown that many Asian and European countries teach introductory algebra in 8th or even 7th grade, and seek to prepare students for that material in earlier grades. Those courses usually aren't called Algebra 1, as they are in the United States, even though they cover algebraic material, he said.

Mr. Schmidt studied algebra and math coursetaking in about 50 foreign nations with varying levels of academic achievement in the mid-1990s; their curricula have remained relatively unchanged since then, he said.

The researcher says he believes all U.S. students should be encouraged to take introductory algebra by 8th grade—and be adequately prepared for it beforehand. In American middle schools today, "there's a tracking," Mr. Schmidt said, in which "some kids get Algebra 1 and others don't."

—Sean Cavanagh

those that can be divided only by themselves and the number 1. For the numerator, 24, they write out 2 x 2 x 2 x 3, for 24. Then she asks them to simplify that expression.

"How many of you got 4/3?" Ms. Wilson asks. Most of the students raise their hands.

Lessons on prime factorization with whole numbers is probably 4th grade material, the teacher says. But that relatively simple skill becomes crucial later in algebra, she points out, when students will be asked to factor using variables and eventually rational expressions.

Her classroom is set up to motivate them for the tasks ahead. A chest-high number line spans the length of one wall. Paper images of famous mathematicians, from Pythagoras to John Nash, the real-life basis for the movie "A Beautiful Mind," hang from the ceiling. Later in the class, Ms. Wilson leads students to Monte Vista's computer lab, where they work on a software program that reinforces the day's lessons visually.

Jill Jordan, 13, uses a mouse to trace a number line on her computer's screen, then clicks to identify the prime numbers.

When she chooses a number, it reconfigures into a series of blocks that show her visually why it is prime or composite, and she moves on to a larger one. At number 91, she misses—it's a composite number, not prime, as she thought—and she's sent back to the 70s.

Jill can easily identify the math that vexes her the most. "Multistep problems," she says. "The ones that go on forever." But she says her confidence has grown over the course of this school year.

Using visual reinforcements, through software and texts, to improve students' math learning was the goal of Matthew Peterson, the creator of the algebra-readiness model for the MIND Research Institute.

Mr. Peterson, 35, co-founded the nonprofit organization while working on his Ph.D in neuroscience from the University of California, Berkeley. His doctoral thesis focused on spatial and temporal processes in the visual cortex of the brain. He now applies visual neuroscience to math.

The scientist had a personal connection to the subject. Mr. Peterson struggled early in school with dyslexia. He didn't learn to read until 5th grade. Math, to him, seemed like an assortment of disconnected facts.

It wasn't until his father, a doctor, encouraged him to use visual clues to help him learn that math and other subjects began to make sense. Even today, he regularly sketches out drawings—on scratch paper, on the whiteboard in his office—to help him remember things and order them.

The pictures and images in the MIND Institute's algebra-readiness textbooks and the accompanying software are meant to have a similar effect on struggling students, Mr. Peterson explained in an interview at the organization's headquarters, in an office plaza in Santa Ana, Calif.

"There's not enough [emphasis] today on how you build visual-learning environments for students," Mr. Peterson said. Many struggling students get lost in multistep problems because they forget the processes needed to solve them. Visual clues act "like a crutch" to remind them, he said.

Another algebra-readiness program, developed at the University of California, Los Angeles, and adopted by state officials, takes a different strategy.

The program provides students with weekly, disposable packets of math lessons, rather than textbooks. The goal is to make the materials less intimidating and more engaging than traditional texts, said Shelley Kriegler, who worked on it as the director of UCLA's Math Content Program for Teachers and Students. To keep it simple and inexpensive for districts to implement, the program does not use computer software.

Struggling students look at traditional, thick math textbooks and "tend to check out," Ms. Kriegler said. Those students, she said, need "a fresh start" with algebra.

New entries into algebra are showing promise at Sierra Intermediate School, in Santa Ana, according to Brad Sterling, a math teacher there.

He's using the MIND Institute's algebra-readiness program, though modifying it slightly to reinforce key math vocabulary—terms like "estimate" and "difference." The school, located in the 55,000 Santa Ana district, is overwhelmingly Latino, and the language-builders help.

Mr. Sterling's first teaching job was at a private middle school in San Diego, where he could give students algebra problems and they would breeze through them. Today at Sierra, students arrive in the 24-year-old's class in need of basics. "Can you help me divide?" he has been asked.

On this day, he begins with addition and subtraction of fractions. Then, using an overhead projector, he asks students to plot fractions on a number line. It's a step toward algebraic thinking.

So far, he believes, the new approach to algebra is helping. His students' skill in number sense and other areas has jumped. Their scores rose sharply on a recent district benchmark test in math. And the visually oriented computer lessons lend variety to his classes, which keeps students interested, he said.

Many of his students see a math book and say, " 'Oh, I can't do it,' " Mr. Sterling explained. The algebra-readiness model, he said, "sets them up to do well in the beginning. It's getting them to the point where they have the confidence to do it."

Special coverage marking the 25th anniversary of the landmark report A Nation at Risk is supported in part by a grant from the Eli and Edythe Broad Foundation.

"You will be more likely to make unwise decisions, and you will find yourself with less control over your life than others who have this knowledge."

–ZALMAN USISKIN

on why algebra is important to people's everyday lives

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FOCUS ON: SCIENCE & MATHEMATICS

Essential Qualities of Math Teaching Remain Unknown

By Sean Cavanagh

It is one of most widely accepted axioms in math education: Good teachers matter.

But what are the qualities of an effective mathematics teacher? The answer, as a recent federal report suggests, remains frustratingly elusive.

Research does not show conclusively which professional credentials demonstrate whether math teachers are effective in the classroom, the report found. It does not show what college math content and coursework are most essential for teachers. Nor does it show what kinds of preservice, professional-development, or alternative education programs best prepare them to teach.

As a result, while the report of the National Mathematics Advisory Panel, released last month, offers numerous conclusions about math curriculum, cognition, and instruction, many of its recommendations about improving teaching are more tentative and amount to a call for more research.

"It is, in some ways, where the action has to come next," said Deborah Loewenberg Ball, the member of the panel who chaired its working group on teacher issues.

"We should put a lot of careful effort over the next decade into this issue so that we can be in a much different place 10 years from now."

The uncertainty about math-teaching skills emerges at a time when policymakers at all levels see a need to boost students' math and science achievement as a key to sustaining the nation's future economic health and producing a skilled workforce.

One reason the panel found a paucity of evidence on effective math instruction is that it set a high standard for the type of research it would accept, as Ms. Ball acknowledged.

Yet its members found a deeper pool of research in other areas of math, such as how students learn in the subject, and how students' confidence in their ability influences their persistence and engagement in math study.

Credentials and Content

The panel was also more confident in calling for "a more focused, coherent" curriculum in pre-kindergarten through 8th grade math—the primary age group studied—with a more logical progression from less difficult topics to more sophisticated subject matter. *(See Education Week, March 19, 2008.)*

But when it came to drawing conclusions about the necessary skills and preparation of educators responsible for delivering that content, the report's authors said much less is known.

On the one hand, effective math teachers have an impact on student achievement, the panel found. It cited a study showing that differences in the quality of teaching accounted for 12 percent to 14 percent of variation in students' math achievement in elementary grades.

But the 90-page report also says it is hard to determine what credentials and training have the strongest effect on preparing math teachers to teach, and teach well. Research has not provided "consistent or convincing" evidence, for instance, that students of certified math teachers benefit more than those whose teachers do not have that licensure, it found.

Similarly, a weak connection exists between teachers' college math coursetaking and the achievement of their students at the elementary level, though there was a stronger link between that educational background and high school achievement, the panel found.

When it comes to the specific math-content knowledge teachers need, the available research is also sketchy, the panel concluded. But the report does offer some direction on that topic.

It emphasizes, for instance, the importance of educators' having a solid grasp of "mathematics for teaching"—or an in-depth knowledge of the specific math needed for their classes and how to make it understandable to students.

Ms. Ball, the dean of the school of education at the University of Michigan in Ann Arbor, conceived that concept, also referred to as "mathematical knowledge for teaching," along with a team of researchers. That work has been widely cited in education policy circles.

Classroom Know-How

Ms. Ball believes the emphasis on giving aspiring teachers more classroom-specific math skills must occur on several fronts.

Schools of education—ideally, entire networks of them—must devise courses and tests, in partnership with mathematics faculty, that provide "instructionally relevant" content knowledge for teacher-candidates, rather than just focusing on more generic math content, she said.

States, which license teachers, should produce certification tests that better measure math teachers' knowledge of instructionally relevant content, Ms. Ball added.

Ideally, states would partner with each other to craft tests using similar standards to cover a wider swath of the teaching population, she said.

Cathy L. Seeley, a former president of the 100,000-member National Council of Teachers of Mathematics, said she also favors emphasizing those classroom skills.

There is a growing recognition of the need to give aspiring math teachers, particularly those who will teach in the early grades, college coursework that is tailored more specifically to working with students, rather than simply piling on more advanced math, said Ms. Seeley, who was not on the math panel.

But shaping education school courses, professional development, and licensure tests around that concept takes time, she said.

"It's a different kind of mathematics and an emerging area," said Ms. Seeley, now a senior fellow at the University of Texas at Austin. "It's not about how much math you have—it's about the particular math you know."

The working group of the math panel that studied teacher issues, like the panel as a whole, placed the greatest value on "scientifically rigorous" research, such as random-

ized controlled trials. The working group acknowledged, though, that conducting such rigorous studies in the area of teacher preparation and content knowledge is difficult.

Many researchers and scholars have bemoaned the lack of firm evidence, not just in mathematics but across subjects, about what preparation and credentials are most likely to produce high-quality teaching. *(See Education Week, April 4, 2007.)*

The dearth of strong research on the attributes of effective teachers applies to science, another high-need subject in many schools, said Heidi Schweingruber, the acting director of the board on science education at the congressionally chartered National Research Council.

Ms. Schweingruber co-directed a 2006 federal study on teaching and learning in K-8 science, which she says revealed a lack of high-quality research on effective teacher preparation and professional development in that subject.

Specialist Knowledge

Establishing a link between teacher preparation and student achievement in many ways represents "the holy grail" in teacher education research, Ms. Schweingruber said. But there are many factors affecting teacher preparation and student performance that can undermine such research, she said.

"Our sense was there was even less known in science than there was in math," she said. The best available knowledge about how to prepare and mentor science teachers, she said, is more commonly rooted in "professional wisdom" than definitive research.

The Institute of Education Sciences, the research arm of the U.S. Department of Education, is supporting a number of research projects on the characteristics and qualifications of effective teachers, and on effective practices in professional development, a spokesman said.

In addition, the IES recently issued a request for applications to set up a Center on Teacher Effectiveness to study the issue in greater depth, though it has not been determined which teacher subject-area would be its focus, the agency said.

On the topic of strategies to recruit and retain math teachers—who are in great demand in districts—the panel said evidence was generally favorable, though not conclusive, that financial incentives help.

Evidence was also mixed on the benefits of elementary school math specialists, who teach only that subject, as opposed to having to cover all subjects, as is common at that level of education. While specialists are used in China, Singapore, and Sweden, the panel's report said, they are not widely employed in most high-performing nations.

Even so, the panel's report urges that research be conducted on elementary-level math specialists, because the potential benefits are so great. Using specialists could be a "practical alternative" to attempting to raise the math skills of all elementary teachers, "a problem of huge scale," the report notes.

Cost is sometimes cited as a barrier to hiring specialists, but another hurdle is the belief that young students benefit from "the nurturing of a single teacher," rather than being taught by a group of them, said Ms. Seeley, who added that she does not buy that argument.

The possible upside of using specialists "is huge," she said. Today, most elementary teachers, as subject-matter generalists, are likely to have taken only one or two college math courses at most, she pointed out.

"I don't care if you have math specialists or not—but I think you should guarantee you have someone teaching math who knows it and likes it," Ms. Seeley said. An elementary math specialist, she added, is more likely to be "someone who knows math and likes it."

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COMMENTARY *Published March 4, 2009*

STEM as a Curriculum

An Experiential Approach

By Jan Morrison & Raymond V. "Buzz" Bartlett

It seems as if the topic of student performance in the STEM subjects—science, technology, engineering, and mathematics—has been with us forever. The level of rhetoric may have diminished somewhat, as the economy's free fall leaves us wondering what the employment future will look like, but concern about STEM education is a constant. While some may question current workforce needs for highly trained people in these fields, no one doubts that an education in STEM subjects is the ticket to a decent-wage-paying career in the economy of the 21st Century.

Because of this economic reality, access to a high-quality STEM education is no longer simply an academic issue, but a matter of equity as well. And how the country responds to it is important for us all.

Unfortunately, too much of the nation's resolve in this area has amounted to arm-waving about the need for more students to be moving through the STEM pipeline toward graduation, and tsk-tsking about the poor performance of American students in the individual STEM subjects on international assessments. Very little energy has gone into determining how to do things differently in schools.

That's not to say there isn't a general understanding about how to teach STEM subjects more effectively; there is. But it struggles to be heard. It is an understanding, moreover, that encompasses all students, including those considered to be nontraditional science and math candidates—precisely the group we must draw from for growth in the STEM pipeline.

This understanding of how best to teach STEM subjects to all is based on the proposition that experiential learning is the ideal instructional vehicle and will appeal in particular to students who ask: "Why do I need to learn this stuff? What's it for? What can I do with it?" Lacking good answers to these questions, such students may tune out school entirely. But effective STEM teaching can counter this impulse. It recognizes that learning occurs most easily when students genuinely interact with ideas.

We must first recognize STEM as a unitary idea, not simply a grouping of the four disciplines in a convenient, pronounceable acronym. The University of Maryland engineering professor Leigh R. Abts has used the term "metadiscipline" to describe STEM, meaning a realm of knowledge that speaks to the presentation of technical subjects as they exist in the natural world, part and parcel of each other. This approach breaks down the boundaries of disciplines devised by and for academia, our historical taxonomy of learning reinforced by Charles W. Eliot and the National Education Association's Committee of Ten in the late 1800s.

Organizing knowledge into disciplines may be useful for research, for delving deeply into the secrets of any natural phenomenon, or for dividing up knowledge into teachable chunks. But it does not reflect the reality or convey the excitement of the world we live in. Neither does it help lead students toward inquiry's counterpoint: solving problems by applying knowledge to design solutions. This is what students will be called on to do in the workplace and in life.

This important point—that problem-solving is interesting to most students—reflects John Dewey's thoughts on the value of experiential learning, and runs counter to the viewpoint prevalent in the 1950s that experiential learning equals career education equals vocational education. Parents railed against that vocational bent, believing their children were all college material and needed to learn in so-called Carnegie units, as required for college admission. Their kids were certainly not in school to be prepared for a career down at the plant.

So our second essential point is this: Effective teaching and learning in both STEM and career and technology education are, practically speaking, the flip sides of the same coin.

Examples of successes in career and technical education, or CTE, include, most notably, the Philadelphia public schools, where students in 34 career academies have achieved a 90 percent graduation rate, 60 percent of those graduates going on to college. An evaluation of the career-academy approach by the research organization MDRC suggests that these schools produce "substantial and sustained improvements in the post-high-school labor-market outcomes of youth."

Another example is the Ford Partnership for Advanced Studies program, launched in 2004 by the Ford Motor Company Fund to help communities develop career-academy networks. It enlists the kind of community support that is needed for career academies to succeed, and its efforts are beginning to show remarkable results.

A recent issue of Maryland Classroom, a publication from the Maryland Department of Education, reports that more than half of those who completed a CTE program in that state "also completed a rigorous academic program that meets the University System of Maryland's entrance requirements." Of equal interest were findings that students in some career clusters—health occupations, graphic design and commercial art, pre-engineering, business-systems analysis and design, and computer programming—outperformed all students, taken as a whole, in Algebra 2, and that students in environmental science/natural resources, pre-engineering, and health occupations outperformed all students in completion of four science credits.

For parents concerned that their career-minded children are being tracked into "voc ed," these results suggest that student engagement in STEM-related career-and-technical education does not come at the cost of academic coursework, and may actually enhance achievement in those courses.

Some states have begun the Herculean effort required to embed this kind of STEM education in their school systems. And Herculean is the right word, for putting in place a multidisciplinary, experiential approach to learning can be as difficult as cleaning the Augean stables.

Our group, the Teaching Institute for Ex-

cellence in STEM, or TIES, has been involved in the creation of the Texas STEM network, a system of seven centers for innovative instruction in STEM subjects and 35 (soon to be 43) STEM schools. We also participated in the development of the Ohio STEM Learning Network, and are working in California, Maryland, New York, and North Carolina. Our observation is that these efforts must be homegrown to succeed. Success will demand, for example, that the community make internships available to all students who need or want them, which requires a level of business and community engagement in local schools beyond what we have experienced in this country before.

It's worth the effort. Research tells us that students in career academies outperform their non-academy peers in a number of categories, including grade point average, test scores, and graduation rates, and that they have lower "scores" in such attitudinal categories as dropout rates, suspensions, and expulsions.

Educators know how to teach STEM. Were they to put this knowledge into action, transforming our instructional approach to these related subjects throughout the nation's schools, the pipeline issues would take care of themselves. And access to STEM careers would open up for those long discouraged and excluded by a tradition of rigidly disciplinary, stand-and-deliver pedagogy.

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