opening the gateway

school districts leading the technology/engineering revolution

National Center for Technological Literacy®

Museum of Science, Boston

contents

What does good technology/engineering education look like and how do we get there?

Shortly after the Museum of Science established the **National Center for Technological Literacy (NCTL)**, teachers and administrators from around the country contacted us, wanting answers to this very complex question.

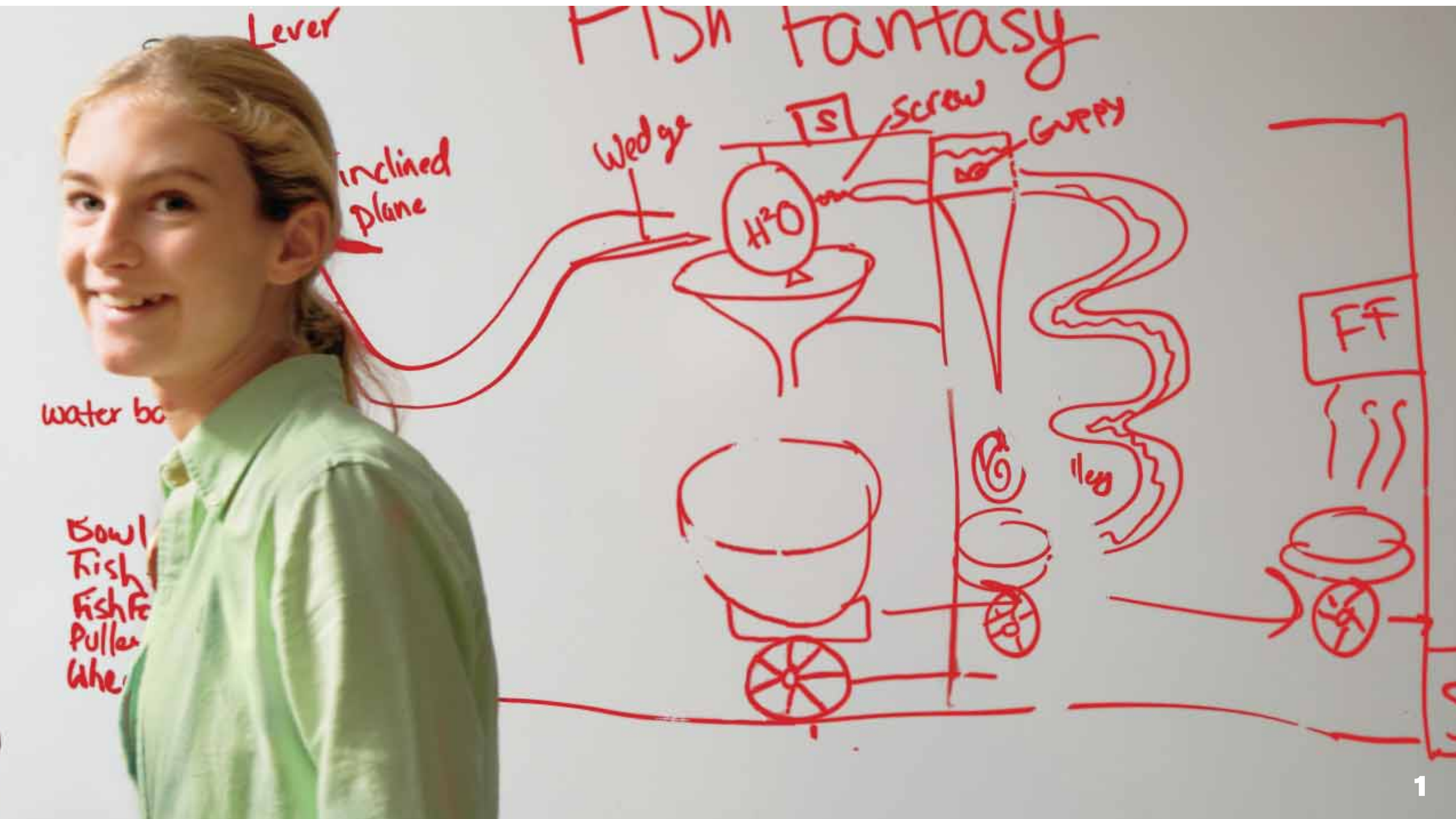
In order to formulate a response, we initiated the Gateway Project, a community of educators committed to opening the way to successful technology/engineering programs for all students K-12.

As a first step toward building the Gateway Project community, we searched for Massachusetts school districts already cultivating strong technology/engineering programs. Because Massachusetts is the first state in the nation to publish educational standards and assessments for technology/engineering, educators here are forerunners in the effort to integrate the discipline in the K-12 curriculum. With funding from the Institute for Museum and Library Services (IMLS), we asked superintendents from these districts to appoint leadership teams of teachers and administrators. This past summer, we invited the first ten leadership teams to the Museum for a week to reflect on challenges and successes, to share the most effective practices, and to formulate action plans for the future.

But that was just a starting point. In the next two years, teams from forty more districts will join the Gateway Project community to exchange strategies and reflect on practice through face-to-face workshops, on-line web casts, and discussion forums. As the network grows district-by-district, information on research and practices will spread to every corner of the state, supporting full implementation of the technology/engineering standards at all schools.

opening the gateway highlights efforts made by ten districts leading the way to effective technology/engineering education for all children. Together, these districts are opening the gates to better learning and teaching across the curriculum. We hope that their stories can be both inspiring and instructive to other school districts joining the national effort to build a technologically literate citizenry.

on the cover: A seventh-grader at the flagship Intel Computer Clubhouse™ at the Museum of Science, a model after school learning environment where young people become confident learners through the use of technology at right: A design for a Rube Goldberg device at the McCall Middle School in Winchester photography: Andrew Brilliant, brilliantpictures.com



Lever
Fish fantasy
Wedge
Screw
Guppy
FF
Bowl

making the case for engineering education

letter from the president

why engineering? why now?

Nearly a century of technological advances have made the United States a political and economic world leader. Technologies unimagined a century ago—cell phones, DVD players, the Internet—dominate the global marketplace. But despite the ubiquitous nature of technology, and its centrality to the U.S. economy, few school districts in our nation include engineering—the study of how new technologies are developed—as a part of the core curriculum.

Now, an educational revolution is gaining momentum. National leaders in government, industry, and education realize we must ensure that our children are technologically literate. Massachusetts took a groundbreaking step toward this goal in 2001, developing the first statewide curricular frameworks and assessments for technology/engineering at all levels preK-12.

what is technological literacy?

In our modern era, technological literacy is basic literacy. Technological literacy means knowing how to use new technologies, understanding how new technologies are developed, and having skills to analyze how new technologies affect us, our nation, and the world. As technologically literate individuals, we can find ways to answer some of the most complex questions of our time, such as: *Should our nation become less dependent on polluting energy sources and, if so, how can we accomplish this? Or how can my city or town direct development so our community is happier, healthier, and more prosperous?*

engineering: a powerful teaching and learning tool

Engineering lessons are project-based and integrate multiple subjects, making difficult concepts relevant and tangible to students and tapping into students' natural interest in problem solving.

For example, a second grade classroom I once visited had a pet rabbit, but one of the children was allergic to it. The students wanted to keep the rabbit, but they also wanted to make sure the allergic student wasn't adversely affected. The teacher asked the class to solve the problem by following the step-by-step engineering design process used by professional engineers to develop new or improved technologies. The students decided to design and build an outdoor habitat for the rabbit. They used verbal and writing skills to explain their plan to their peers, teacher, and principal. They used math skills to measure the rabbit and calculate the dimensions of the new habitat. They learned about the rabbit's biological needs and even devised a way to protect the habitat from the neighborhood raccoon. This lesson engaged students of all abilities and talents in a collaborative learning process.

preK-12 engineering broadens the pipeline.

In the twentieth century, the U.S. led the world in industry and engineering. To maintain that leadership, we need to ensure that well-trained, highly creative Americans continue to enter the field of engineering. Currently, most engineering schools lose between 30 to 50 percent of the freshman class to liberal arts programs, and the United States graduates fewer engineers than many developed and developing nations. To maintain our competitive edge, it is critical that we, as a nation, attract students to the engineering profession—and keep them there.

To do so, we must open the profession of engineering to women and minorities. Although these groups have advanced in other professions, such as law and medicine, engineering remains a decidedly white and male profession. A very low percentage of female and minority students enters engineering colleges, and attrition rates are highest among these groups.

Teaching young students about engineering can help solve the problem. Studies have shown that if a student encounters engineering early on in school, he or she is more likely to choose engineering as a career. Positive experiences of engineering during the early years can also inoculate students against erroneous cultural messages about who should study engineering.

In this light, engineering education can be thought of as a pathway of experiences, starting in kindergarten and extending to high school and beyond, that gives students skills and knowledge they will need to consider entering the engineering profession. Broadening the pipeline is not only about filling a national need for engineers, but also about making sure that every student has the opportunity to pursue a career that can be both lucrative and intellectually rewarding.

To help lead the preK-12 technology/engineering revolution, the Museum of Science, Boston established the **National Center for Technological Literacy (NCTL)**. The goal of the NCTL is to integrate engineering as a new discipline in schools nationwide and to inspire the next generation of engineers and innovators. We partner with educators, administrators, organizations, and industry representatives across the United States to introduce or modify standards related to technology and engineering and to provide cutting-edge curricular resources. Working together, we can engineer a better world for generations to come.

Sincerely,

Ioannis (Yannis) N. Miaoulis
Director of National Center for Technological Literacy
President and Director, Museum of Science, Boston

a new framework for

In 2001, Massachusetts started an engineering revolution when it became the first state to mandate and test technology/engineering learning standards for students in grades preK-12.

The publication of the *Massachusetts Science and Technology/Engineering Curriculum Framework* was a tremendous boon for districts across the state. "The standards give us an invaluable tool; they give us a target. Using them, we can create curriculum, assess student learning, and identify gaps in teaching through the grade levels," says Yvonne Spicer, director of career and technical education in Newton Public Schools.*

this page, clockwise from top left: 1. Technology teacher Sandy Chaet demonstrates a magnetic levitation vehicle to her sixth grade class. 2. Teaming up to teach engineering at Newton South High School 3. Yvonne Spicer, director of career and technical education in Newton Public Schools 4. A student shares a page of her engineering notebook.

* In January, 2006, Spicer will begin her tenure as associate director for the National Center for Technological Literacy at the Museum of Science.

According to Spicer, placement of the technology/engineering standards within the science frameworks formalizes the interconnectedness of science, technology, and engineering in a highly visible way and challenges traditional attitudes about technology education. "For the past 100 years technology education has been perceived as only appropriate for those students who are less capable," says Spicer. "The *Science and Technology/Engineering Curriculum Framework* sends a message that the technology laboratory is actually an ideal place for rigorous instruction that is also hands-on and engaging to all students."

Using the *Framework* as a guide, high school technology and science teachers in Newton have collaborated to develop an integrated, team-taught engineering course. The course fulfills the freshman-year physics requirement and prepares students for engineering offerings in subsequent grades. Every project offers ample opportunities to teach physics and engineering skills. As students design and build a mousetrap car, for instance, they learn about the coefficient of friction—a science concept—and then use this knowledge to select wheel materials and improve vehicle performance—an engineering design challenge.

The approach to teaching has been a hit with students and parents alike. Student demand has overwhelmed facilities, a problem that will be resolved as soon as construction of new technology laboratories is completed later this year. Teachers

learning

report that parents want to see an integrated approach to instruction in other classes at the high school. “We hope to make this the model for science instruction in many more of our classes,” says Charles Myette, physics teacher and housemaster at Newton South High School, and an original developer of the course.

a constantly evolving profession

Collaboration between science and technology departments in Newton also solves a problem posed by publication of the state’s technology/engineering standards: the standards go further into science and math than many technology teachers feel comfortable venturing. “Technology teachers are well-versed in hands-on pedagogy and know the science content, but they often need help communicating that content to students,” says Spicer. “That’s where working with the science department can really make a difference.”

In Newton, partnering technology and science has boosted learning at all grade levels. The K-8 science coordinator has worked with teachers in elementary and middle school grades to map curriculum and find areas where it does not align with state standards. The teachers and administrators have also analyzed student scores from the state’s standardized test, the MCAS, to identify holes in teaching and learning.

“At the middle school level, we found most holes in the physical sciences. And we saw that technology teachers could deliver a lot of the physical science content through their hands-on technology/engineering courses,” Spicer says. To help facilitate this, Spicer dedicated one-half day each month for middle school science and technology teachers to come together to share ideas, reflect on their craft, and integrate their efforts. The teachers, who are spread between several middle schools around the city, also developed a web site to facilitate ongoing communication.

The *Massachusetts Science and Technology/Engineering Curriculum Framework* may have pushed some educators out of their comfort zone. But as lifelong learners, most teachers are ready and willing to set out into uncharted territory. “Our jobs are constantly evolving,” says Spicer. “That’s the beauty of our profession.”

> ***“The [state] Framework sends a message that the technology laboratory is actually an ideal place for rigorous instruction that is also hands-on and engaging to all students.”***

constructing a pipeline

To engineers, a pipeline is a system for moving materials over great distances. To engineering educators, however, the term "pipeline" has come to refer to the pathway of experiences, from kindergarten to high school, that prepare students to succeed in the designed world.

Just before the end of the twentieth century, Worcester Public Schools decided to construct such a pipeline in the Doherty Quadrant, one of four sub-districts of the large, urban school system. "We started looking at the labor statistics about how few engineers our nation trained. And we looked at low science and math scores nationwide. To me, the relationship was clear," says Dennis Ferrante, a director in the Worcester Public Schools who has overseen and supported the development of the Engineering Pipeline. Ferrante saw an opportunity to improve student learning in math and science through the discipline of engineering. The news of state standards for technology/engineering only bolstered the plan.

Limited resources, funding, and staff training posed significant challenges, so the district drew on the support of local colleges, universities, and engineering-related businesses. These partners—including Intel Corporation, Worcester Polytechnic Institute (WPI), Raytheon Company, the Manufacturing Assistance Center, Quinsigamond Community College, the Carnegie Foundation, and FIRST Robotics—provided brainpower and real-world expertise, and helped woo funders for the Doherty Quadrant's engineering makeover.

"At the bottom line, enlightened self-interest is the secret to bringing community players together," says Worcester Public Schools superintendent James Caradonio.

from left to right: 1. Midland Street School sixth-graders pose by a wheelchair they have designed. 2. Students in the Engineering and Technology Academy at Doherty Memorial High School demonstrate an electric car that responds to sound. 3. A student reviews architectural plans. 4. A student from Worcester Polytechnic Institute helps with an engineering lesson in a Midland Street School second-grade classroom.

"WPI wants a more diverse student body, and we want to see more of our students go to WPI. Local industry leaders need better trained workers, and we want our students to graduate with the skills they'll need to succeed."

community involvement: the secret to success

Community support has played a key role in building the pipeline. Through a National Science Foundation grant, WPI students and professors work with teachers from the Quadrant's elementary and middle schools to develop engineering lesson plans and teacher manuals. Youngsters visit the close-by college's design laboratories, and WPI students serve as resources for teachers in Doherty's elementary and middle school classrooms.

"All of the children have a chance to get to know a diverse group of college students who are becoming engineers," says Patricia McCullough, principal of the K-6 Midland Street School in the Doherty Quadrant. This makes engineering seem within reach. "That's exactly the point of bringing it to the elementary level," she says. "You have to start early before the children get any notions that only certain kinds of people can become engineers. We tell them, 'If you want to become an engineer, you can.'"

Worcester administrators asked industry advisors to help identify the skills older students must have before entering the profession. "They said over and over that students needed to learn basic team work and communication skills. Those are the skills that they really saw lacking in the hiring pool," says Katerina Kambosos, who coordinates the Engineering and Technology Academy at the 1,500-student Doherty Memorial High School.

The Engineering and Technology Academy is open to approximately 300 students who reside in the quadrant. The Academy offers a more personalized approach to learning and ensures that students form lasting relationships with peers and instructors. A guidance counselor follows each student's progress with an eye on grades, standardized test scores, and college plans. The counselor works closely with teachers and parents to identify and remove obstacles to student achievement. "The idea is that no one will slip through the cracks here," says Kambosos.

The engineering focus blends math and science in creative projects. Math, science, and engineering teachers meet twice a week to coordinate their lessons across the disciplines. For more real-world experience, every senior completes a practicum at a local engineering business. Many have gone on to take internships and, later, salaried positions at their practicum sites. But, as teacher John Staley says, "The Academy is not designed to crank out engineers. It's designed to prepare students to do whatever it is that they want to do."

"You have to start early before the children get any notions that only certain kinds of people can become engineers. We tell them, 'If you want to become an engineer, you can.'"

engineering 101

Across all subjects and grade levels, teachers sing the praises of hands-on, experiential learning opportunities—the kind that high-quality technology/engineering education delivers.

But elementary school teachers face some unique obstacles to adding technology and engineering to their instructional repertoire. According to teachers at the Peter Noyes Elementary School in Sudbury, many of these obstacles are based on some common misconceptions about technology and engineering—and with focused professional development, a good number of them disappear.

"When most of us think of technology, we think of computers," says Becky Drake-Hedin, a second-grade teacher at the Peter Noyes Elementary School. And the very term "engineer" conjures the old stereotype of a brainy scientist spouting mathematical formulas.

Some basic education about what technology is and what engineers do can offer teachers reassurance that they don't need to master differential equations and quantum physics to implement the state standards at the elementary level. "The fact is that elementary teachers meet a lot of the technology/engineering standards with what they are already teaching," says Drake-Hedin. "They just don't realize it."

For instance, as a part of a unit about weather, second-grade students design and build simple weather instruments. And as a part of a unit on soil, third-graders design and build a compost bin. Both activities offer many opportunities to use the engineering design process and select materials for specific tasks—which meet the state standards for technology/engineering.

This is good news for time-strapped teachers who are already packing their students' days to meet an ever-increasing set of learning standards. "Elementary school teachers feel that they don't have time to do this. But they all put a premium on critical thinking. They all do problem-solving activities," says Karen McCarthy, K-8 science curriculum specialist in Sudbury. "If we let them know how they are already meeting the standards, they can make that explicit to students."

In Peter Noyes Elementary School, Becky Drake-Hedin recently led a 45-minute workshop in which teachers worked in teams to solve a design problem: building a bridge out of recycled material that could hold up a plastic cup full of steel washers. After building bridges, the group brainstormed how they could bring out the technology/engineering lessons already in the curriculum. All the while, the teachers broadened and refined their ideas about what technology is and what engineers do.

another lens for problem solving

Less than an hour south, Andrea Plate, who directs math and science K-8 in Foxborough Public Schools, has a similar message for her teachers. According to Plate, the engineering design process has a lot in common with other problem-solving approaches already taught in elementary and middle school classrooms. "The engineering design process runs parallel with the scientific process and mathematical problem solving," says Plate.

This message is critical for teachers—and for students—to hear. For teachers, it means that technology/engineering is not just an add-on but integral to what's already going on in the classroom, says Plate. And it helps students make connections between subjects that they might not find otherwise. "It's essential to help students see the similarities between the critical thinking processes that they use in each subject," she says. "Whether solving a math problem or analyzing literature, you're using many of the same steps for thinking the problem through."

To spread the word, Plate challenges teachers at professional development workshops to design a system for manufacturing pinwheels using construction paper, scissors, tape, straws, and a few other items commonly found in the classroom. Teachers then test their system by seeing how many pinwheels they can produce in ten minutes.

The activity demystifies concepts about engineering, technology, and manufacturing. It also gives teachers a chance to evaluate and redesign the system—important steps of the engineering design process and steps that are key to reinforcing student learning, says Plate. "How often do we challenge students to reflect on what they've done and find ways to improve it? Doing so can increase learning across the subjects."

"[Elementary school teachers] put a premium on critical thinking. They all do problem-solving activities…. If we let them know how they are already meeting the standards, they can make that explicit to students."

above: Designing a bridge from recycled materials at the Peter Noyes Elementary School in Sudbury during a professional development workshop from left to right: 1. Andrea Plate, director of math and science K-8 in Foxborough Public Schools 2. Teachers at the Peter Noyes Elementary School prove that learning about engineering can be fun. 3. Teachers at the Ahern Middle School in Foxborough troubleshoot their pinwheel manufacturing system. 4. More revelry at the Peter Noyes Elementary School in Sudbury

state of the art

How much should school districts invest in technology/engineering facilities and equipment?

At Framingham High School, a combination of careful planning and fortuitous timing has allowed technology educators to develop a multimillion-dollar cutting-edge facility that offers students the opportunity to develop skills by using the kinds of technologies they will encounter in the working world.

Not every district will choose to invest in technology education in the way that Framingham has. But according to Steve Eaton, director of technology education and engineering in grades 6 through 12 in Framingham, the return on investment is better teaching and learning. "As a technology educator, I have a tool box for teaching. That tool box contains the engineering design process, science, math—and technology itself," says Eaton. "Technology is one more tool I can use to pull students in."

Over the past five years, educators at Framingham High School have worked with members of industry—and have drawn on their own collective experience—when designing laboratories and purchasing technologies for the department. Now the high-tech tools at the high school include the same computerized electronics analysis system used by the military for training purposes; programmable robotic arms that connect with manufacturing conveyer belts for teaching computer-aided manufacturing and robotics systems; a woodworking laboratory with a professional-grade Computer Numerical Control (CNC) milling machine, which can be programmed to fabricate prototypes and parts out of a variety of materials; and a pre-engineering laboratory where students take, for either science or tech-ed credit, a course co-taught by physics and technology education teachers.

The high school's Technology Education/Engineering department also boasts a graphic design classroom with an offset printer; multiple photography classrooms equipped with student-designed dark rooms; rows of Macintosh computers for digital processing and Computer-Aided Design; and a high-end video production studio where students produce an Emmy Award-winning television show that is broadcast to the Framingham community.

Despite the dazzling devices, the highly engaged students, who fill every laboratory, take center stage. "The focus is not the keyboard or the drill press or the CNC," says Denise Barlow, a former electrical engineer who now teaches electronics and architectural design at Framingham High School. "Students use the tech-

nology to design and build. That's the real focus." That approach to learning has broad appeal. While one course in technology education is required, many students take courses in the department all four years. Over one-half of the school's 2,000 students take technology courses annually.

building a case for technology/engineering

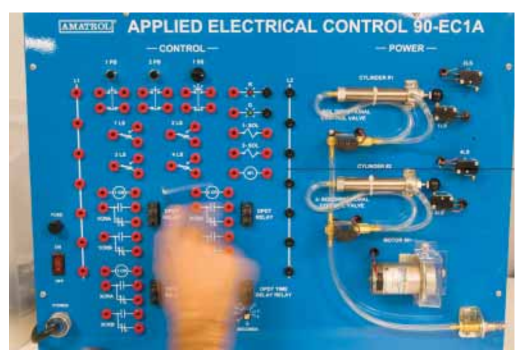
Like all of the teachers in the department, Barlow brings real-world experience to her job—and also holds a technology education teaching certificate. Even the graphic design and photography teachers are certified in technology education or are working toward certification. According to Eaton, tech-ed training is essential preparation for the job. "Technology teachers have to be Renaissance people," says Eaton. "They do it all. They have to know the engineering design process, they have to know how to use technology, they have to know the science, and they have to know people."

All of the teachers in the department integrate the engineering design process and relevant science and math concepts in every project.

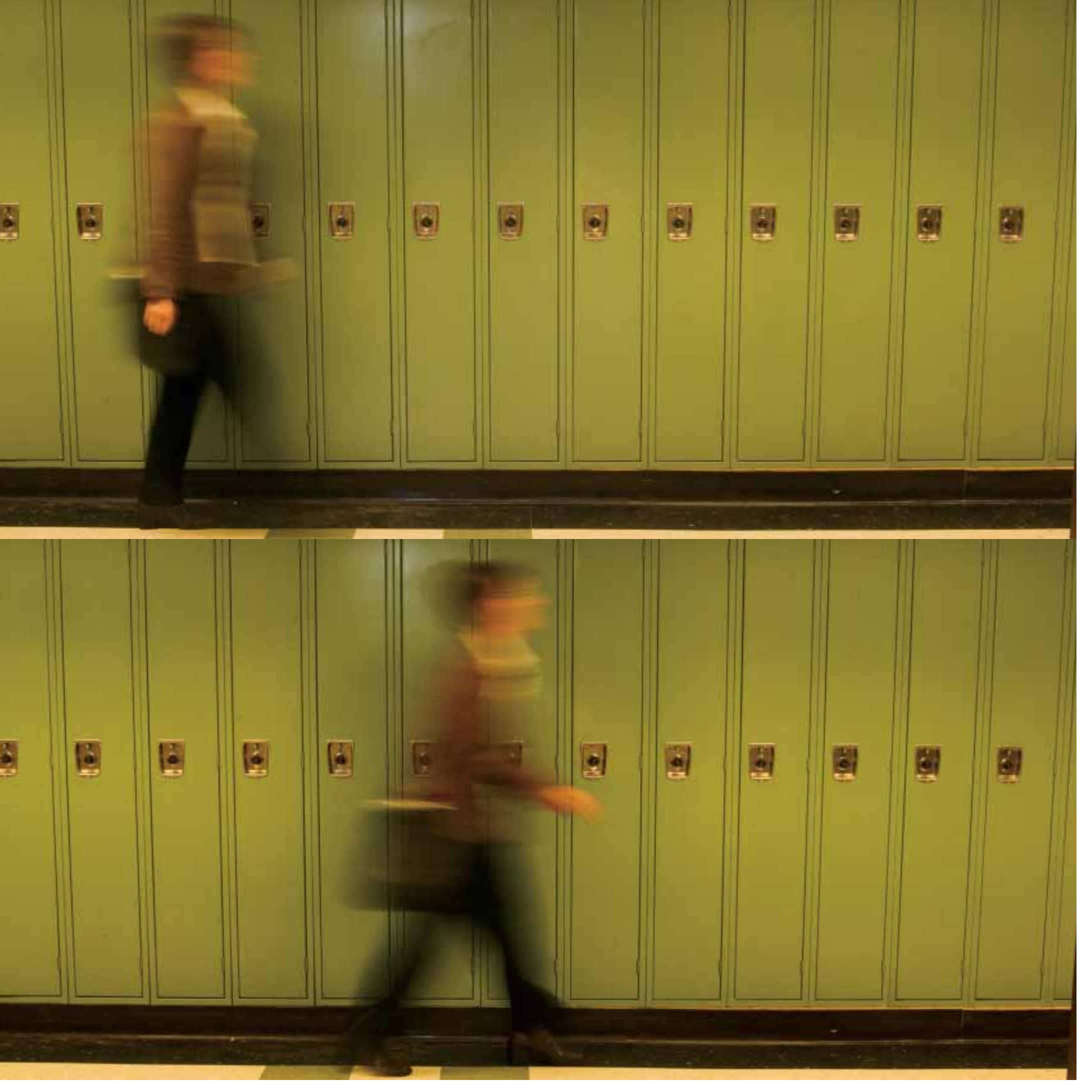
Framingham is a socio-economically diverse community, with more than a quarter of the district's students classified as low-income. So how did technology educators in Framingham High School convince the district to invest so heavily in technology education? Four years ago, the high school underwent a complete renovation. The Technology Education/Engineering department seized the opportunity to analyze curricular needs, the needs of students, and long-term goals for the program. By examining the national need for engineers and technicians and the vital importance of giving students practical skills, they built a compelling case. Then they dreamed big when they made budgetary recommendations to the district—and they received much of what they asked for. Even so, Eaton and his team must continually seek out funding from the district and elsewhere for maintenance and upgrades.

Now students at Framingham High School can follow focused pathways of course work in computer systems, construction technology, engineering, manufacturing and transportation technologies, and communications. All 32 technology education/engineering courses are designed to help students learn how to use tools to develop critical and creative thinking skills and to better understand the technological world. Students thereby learn valuable skills that they can use after graduation—whether they go on to college or directly into the working world. "There isn't a job out there where students won't use technology or some form of the design process," says Eaton. "These skills are survival skills."

"As a technology educator, I have a tool box for teaching. That tool box contains the engineering design process, science, math—and technology itself."



clockwise from bottom left: 1. Former electrical engineer Denise Barlow troubleshoots a circuit design with her students in an electronics class at Framingham High School. 2. Steve Eaton directs technology education in grades 6-12 in Framingham. 3. A design laboratory full of school spirit at Framingham High School 4. A student practices reading the daily news to a camera in Framingham High's production studio. 5. A device used for teaching electronic control of hydraulic and pneumatic systems



back to school

Problem: The majority of Americans have little idea what engineers do.

Solution: Bring engineers back to school to teach young students about their profession.

That's the approach taken by technology teachers at McCall Middle School in Winchester, a tree-lined suburb of Boston. Each spring, the school brings over 30 working engineers, who also happen to be parents of Winchester students, to campus for an event that would rival any professional-grade conference in terms of variety and enthusiasm.

During Engineer's Day, middle-school students attend workshops in engineering disciplines ranging from acoustic to structural. The students build rockets, test products, and even try their hands at podiatric surgery using the newest surgical instruments. "At the end of the day, they can tell you what engineers do," says Charlie Corley, director of technology/engineering in Winchester Public Schools.

Engineer's Day was the brainchild of middle and high school technology teacher Rich Monagle and middle school social studies teacher Evelyn Galatis. Monagle observed that students coming into his courses had little understanding of the engineering profession and no real sense of how the concepts they were learning applied to the real world, so he invited engineers to his class to tell the children about their work. The popularity of these visitors spurred him to think bigger.

Now, the festival supports learning that happens all year round in Winchester. Every middle school student also takes hands-on technology and engineering courses. Monagle and Corley designed the courses to map directly to the Massachusetts frameworks for technology/engineering at the middle school level. A visitor to Monagle's eighth-grade technology class would see teams of engaged students designing and building Rube Goldberg devices that incorporate simple machines such as levers, pulleys, and gears along with the use of a microprocessor. The whimsical devices make toast, blend smoothies, spray room deodorizer—any creative application the students can imagine. The interjection of fun into the design process keeps students hooked—and keeps things interesting for teachers.

Middle school courses on manufacturing, structures, transportation, design, and robotics using hydraulics and pneumatics ensure that all students—including girls—receive a thorough introduction to technology and engineering before moving on to the offerings in high school. "I really see little difference in the girls or boys at this level in terms of ability or interest. If anything, the girls are more open and enthusiastic," says Monagle.

By the time they get to high school, however, fewer girls elect to take technology/engineering courses—reflecting a national trend that may partly account for the gender gap among engineering professionals.

To provide role models for girls, the teachers make sure that a representative number of professionals at Engineer's Day are female. These female engineers prove that the profession is open to women who are interested in entering it, says Corley. Teachers have found that the presence of women professionals at Engineer's Day and extensive course work during the middle school years does help to extend girls' interest.

Of course, not every student will make the same professional choice as the visitors they meet during Engineer's Day. "We're not going to get every student to become an engineer," says Corley. But by meeting real, working engineers, students will gain a deeper understanding of what engineering is—and a few may have a memorable experience that will directly impact their future career choices.

"Our main goal is just to let them know that the field is open to them," says Corley.

"[B]y meeting real, working engineers, students will gain a deeper understanding of what engineering is—and a few may have memorable experiences that will directly impact their future career choices."

at left: 1. Photos of Engineer's Day courtesy of Winchester Public School District above: 1. Students build Rube Goldberg devices. 2. Charlie Corley, director of technology/engineering at Winchester (left) and Richard Monagle, middle and high school technology/engineering teacher
3. Building Rube Goldberg devices

building a culture

High school sophomore Alafia Spencer had known for years that she wanted to become an engineer. But the Hyde Park High School, the 1,100-student school Spencer attended in Boston, did not offer the courses that would help her pursue her dreams.

Spencer did not let that stop her. When district leaders announced plans to break down Boston's large high schools into smaller learning communities—with financial support from the Carnegie Corporation of New York and the Bill and Melinda Gates Foundation—Spencer saw an opportunity. She developed a detailed proposal to make one of the small learning communities into an engineering school.

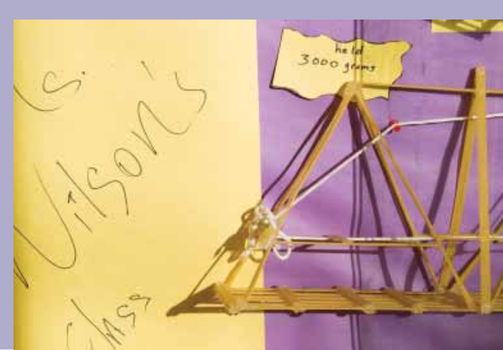
"We already had an engineering lab in the basement that wasn't being used," she said. The demographics of the school also made engineering a compelling choice. "We need more minority students in engineering, and we have minority students here."

The district selected the proposal, and in September 2005, The Engineering School opened its doors to 385 students. The new school is one of three small schools housed in the former Hyde Park High School, each with its own curricular theme. "It's everything I had hoped it would be and more," said Spencer, now a senior at the school she helped design. "We have hands-on design projects. We get to know our teachers better. It's great."

a district-wide effort

The Engineering School launched amid a district-wide push to boost technology/engineering instruction in Boston's public schools. Budgetary constraints, lack of professional development opportunities, and pressure to raise student scores on the math and English/language arts portions of the MCAS, the state's achievement test, had weakened science instruction. In 2004, only ten percent of the district's eighth graders scored at the proficient level or above on the science portion of the MCAS.

As a result of these and other indicators, the district has initiated a K-12 science and technology reform effort. A new $12.5 million-dollar grant from the National Science Foundation supports a collaboration between the University of Massachusetts, Boston, Northeastern University, and Boston Public Schools to invigorate science instruction, bolster professional development for teachers, and integrate technology/engineering into the



# of trust

curriculum. At the same time, an ongoing partnership with Machine Science, a nonprofit organization that provides engineering curriculum and instructor training, offers after-school engineering experiences to students. And TechBoston, a department within the district, works to integrate technology into the middle and high school curriculum, as well as to train students to provide tech support and web development services to Boston-based businesses and organizations.

building from the ground up

The formation of The Engineering School symbolizes another giant step toward better science and engineering instruction in Boston Public Schools. But the biggest challenges lie ahead for the fledgling school. Students, teachers, and administrators are currently developing an instructional plan that includes raising the school's math graduation requirement from algebra II to calculus, and ensuring that all students take higher-level science courses in addition to engineering.

In the school's first year, incoming students lacked the preparation to move into advanced science or math courses. "We're having to do a lot of skill-building to get students up to speed," said Erica Wilson, an engineering and physics teacher at the school. Wilson is pilot testing Engineering the Future, an introductory engineering course being developed by the Museum of Science. The course is designed to be taught in a range of facilities, and equipment and materials requirements are flexible. As The Engineering School finds more funding, develops its program, and adds more specialized courses over the next several years, it can tailor Engineering the Future to utilize new equipment and facilities.

But building an engineering school isn't just about developing an instructional plan. The entire school community must focus on creating a culture of trust, says Mweusi Willingham, The Engineering School's headmaster. "A big part of engineering is learning from failure. At an engineering school, teachers must be willing to allow students to make mistakes and learn from them," he said. "And students must be made to feel that it's safe to learn from their mistakes." Willingham says that administrators can model this instructional philosophy by encouraging teachers to try new things and analyze the outcomes to improve practice.

Evidence of the benefits of more student-centered learning is already sprouting up in classrooms, says Erica Wilson. She reports that students in her engineering classes relish the opportunities to build and create. And the fact that students play a key role in decision-making heightens their level of investment. "I think the sense of the high school has totally changed from what it used to be," she says. "We're really trying to encourage a feeling of professionalism among the students, and they are responding to that."

top: Alafia Spencer, senior at The Engineering School
bottom (from left to right): 1. The Engineering School students discuss the best way to design a prototype for a DVD organizer. 2. Spaghetti bridges on display in the lobby of The Engineering School 3. A senior in an Engineering the Future class 4. Mweusi Willingham, headmaster of The Engineering School

"A big part of engineering is learning from failure. At an engineering school, teachers must be willing to allow students to make mistakes and learn from them… . And students must be made to feel that it's safe to learn from their mistakes."

hands-on

The best teachers know that there are many different kinds of learners: the kinesthetic learner who excels at building, the visual learner who needs to sketch ideas, the verbal learner who must discuss and communicate ideas in order to understand them—to name only a few.

Engineering lessons can appeal to them all and are powerful tools for helping every student understand abstract math and science concepts.

In Massachusetts school districts, teachers report that, whether they use off-the-shelf curriculum packages or develop their own, hands-on engineering lessons can boost engagement, enthusiasm, and learning in all grade levels.

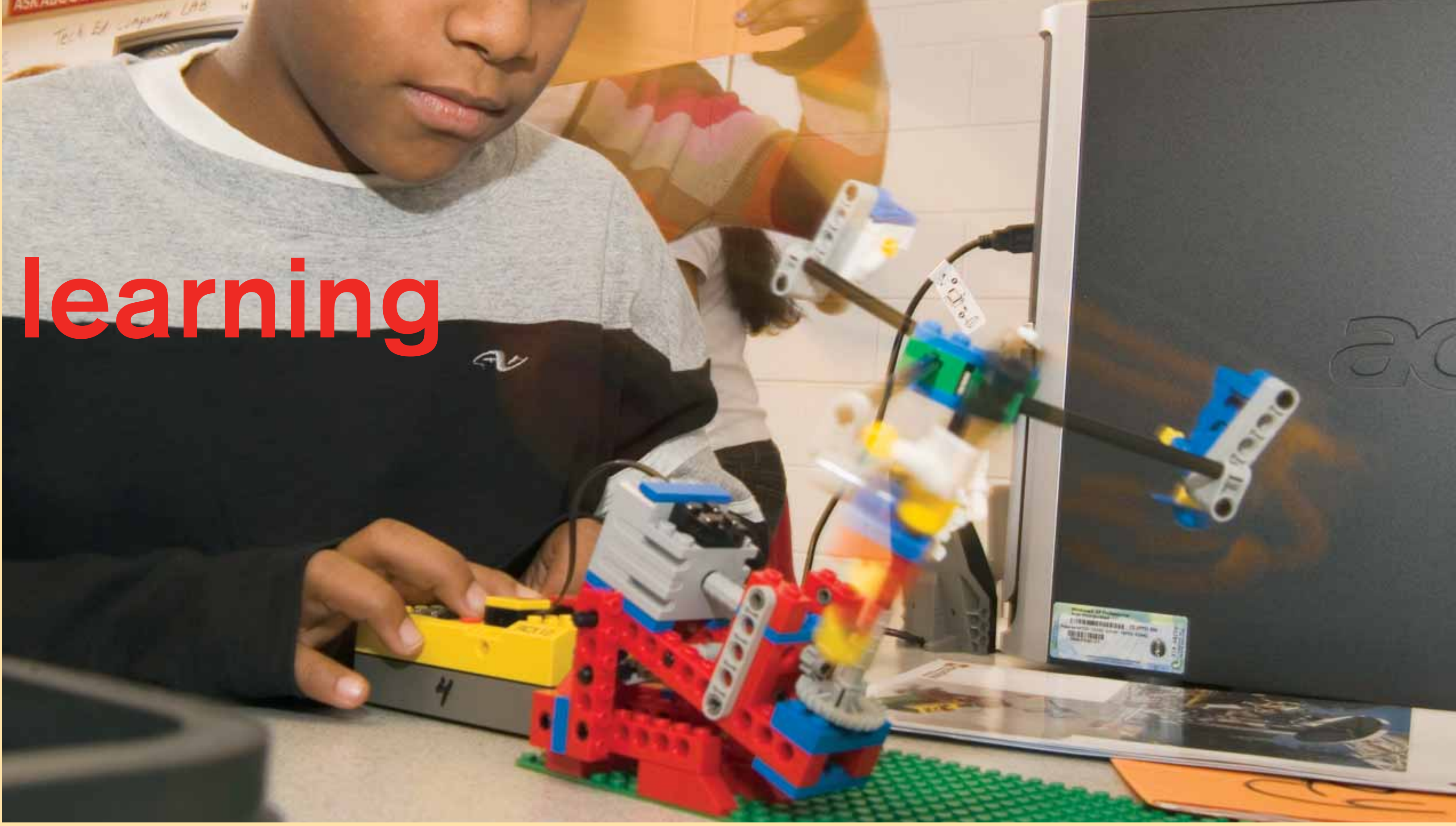
making connections to the real world

Fall River Public Schools

At B.M.C. Durfee High School in Fall River, one environmental engineering class recently tackled the faulty design of a nearby landfill that was polluting a local stream. Their data and recommendations proved so persuasive that they were used as a part of a class action lawsuit against the landfill. Another engineering class is working with a local engineering firm to develop a system for "renaturalizing" some of the former wetlands areas on which the campus athletic fields were built.

These real-world projects reach students who are unmoved by traditional lecture-style classes, according to Christopher Boyle, director of the science and engineering department at Durfee. Students care deeply about the projects because they are working to solve problems right in their own backyard, which motivates them to tackle the tough science and math concepts that otherwise might seem intimidating. "It used to be that it was up to the students to find their own way to stay interested in what they were learning," Boyle says. "But now we know more about how students

from left to right: 1. Students at the Matthew J Kuss Middle School in Fall River making radio contact with astronauts on the International Space Station 2. A student at Dover-Sherborn High School displays a guitar that he designed and built. 3. A forensics class investigating "evidence" at B.M.C. Durfee High School in Fall River 4. A LEGO/Logo laboratory at Collins Middle School in Salem



learning

learn. We know now that you need to design lessons that have a hook built-in. It's just a more effective way to teach."

So when high school administrators said they needed a detailed map of the high school to give to police for use during emergencies, Computer Aided Design (CAD) teacher Leo Sirois challenged his students to create 2-D and 3-D versions of it. Now, visitors at Durfee use student-drawn maps to navigate the enormous and highly complex building.

Fall River's dedication to technology/engineering extends through the grade levels. The Matthew J Kuss Middle School was one of fifty schools chosen to take part in a three-year NASA Explorer Program, which offers funding and curricular support for math, science, and technology instruction. Kuss Middle School students recently contacted astronauts on the International Space Station by short wave radio as a part of the NASA Explorer School Program.

At the elementary school level, teachers are piloting Engineering is Elementary (EiE), a curriculum being developed by the Museum of Science. The curriculum offers engineering lessons that integrate with elementary school science topics and connect to widely used science curricula. In one EiE unit, students design and improve hand pollinators as they learn about insects, plants, and agriculture. In another unit, students explore materials engineering as they develop their own mini versions of the Great Wall of China.

fine-tuned instruction

Dover-Sherborn Regional School District

What does electromagnetism have to do with Jimi Hendrix or the Rolling Stones? The technologies used by these musicians take advantage of the relationship between electricity and magnetism to amplify and alter sound. Students at Dover-Sherborn High School explore these physics concepts and others as they design, build, test, and redesign their very own electric guitars.

Designing and building a functioning electric guitar with almost no pre-fabricated parts is a complex undertaking, but this is not a cookbook activity. Teacher Joshua Bridger offers no step-by-step manual—just the supporting physics concepts, a laboratory full of materials, and many words of advice. Students in Bridger's class learn by doing—and, often enough, by making mistakes. "Some of the most rewarding laboratory work I have ever done has been a result of taking on the research, design, and implementation of a project by myself," says Bridger. "The errors were my own, but the results and successes were as well. I want [students] to feel this way about [their work]."

continued next page

hands-o

Throughout the semester-long project, students study magnetic induction by building guitar pick-ups, which use magnets to translate sound waves into an electric current. They apply what they learn about the relationship between current, voltage, and resistance as they wire volume and tone control knobs onto the guitar. They study how vibrating strings produce sound and how the tension and length of the string affects pitch. They even learn about mechanical advantage and forces as they install and use tuners on the guitar heads. All the while the project keeps students focused on a subject that most teens find inherently interesting: rock and roll.

This project builds on a range of engineering experiences students in the district encounter in other courses, such as building bridges, constructing Rube Goldberg devices, and designing solar-powered vehicles. At the middle school level, students use Scan TEK Modules, a computer-based instructional system that introduces them to a variety of hands-on technologies used in the workplace.

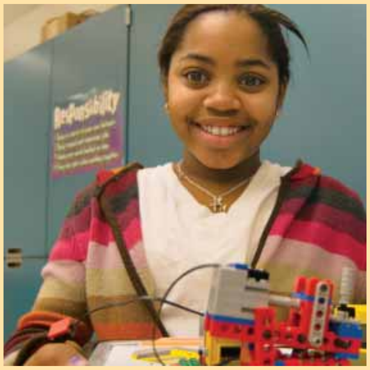
shifting paradigms

Salem Public Schools

Before developing a strong engineering program, Salem High School faced a common problem: college-bound students believed that courses in the technology department were not academically rigorous enough to help them get where they wanted to go. Consequently, they didn't sign up for those courses. "Some of the more academically inclined students wouldn't even look at courses in that part of the catalogue," says Martha Hogan, who heads the science department at Salem High School.

To make sure every student had access to rigorous engineering instruction, Salem High School joined Project Lead the Way (PLTW), a non-profit organization that has developed a four-year sequence of engineering courses designed to give students the skills they will need to enter engineering colleges. PLTW courses are academically challenging and focus on hands-on, team activities.

upper left: A very popular Computer Aided Design class at B.M.C. Durfee High School in Fall River
lower images from left to right: 1. A proud student at the Collins Middle School in Salem displays her newly designed robot. 2. A student at the B.M.C. Durfee High School in Fall River 3. and 4. Learning about sound while designing and building electric guitars at Dover-Sherborn High School 5. Students at the Matthew J Kuss Middle School in Fall River 6. Building LEGO/Logo designs at Collins Middle School in Salem



n learning continued

Now, students at Salem High School can take college-preparatory courses such as engineering design, digital electronics, and architecture.

In addition to offering extensive professional development to teachers, PLTW also trains guidance counselors to better understand the merits of engineering education so they can communicate those merits to the entire school community. Making this information available to Salem students and parents has helped convince them that engineering courses are worth taking.

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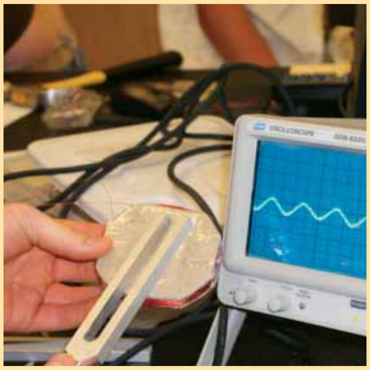
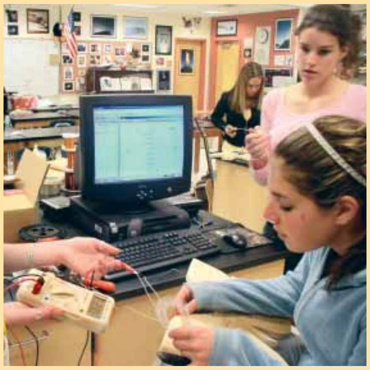
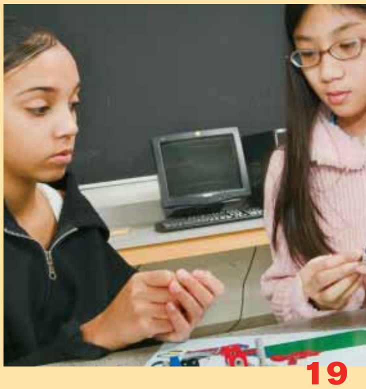
At the Collins Middle School in Salem, teachers and administrators recently built a new LEGO/Logo teaching facility, and are piloting a LEGO/Logo program with sixth-grade students. In one LEGO/Logo lesson, students build small merry-go-rounds out of LEGO building blocks, gears, motors, and sensors. They then connect their machines to a computer and write computer programs, using a modified version of the Logo computer language to control the machines.

The LEGO/Logo lessons help students meet the Massachusetts state technology/engineering learning standards involving the engineering design process and simple machines. But beyond that, LEGO/Logo activities, such as constructing the merry-go-round, can appeal equally to both girls and boys, says Ellen Dufour, math/science curriculum coordinator at the Collins Middle School. "All students have a good time using LEGO/Logo. That's important. It keeps students engaged and excited about learning," she says.

The LEGO/Logo lessons are just one of many ways that teachers at the Collins Middle School make learning fun for students. Over the sixth-, seventh-, and eighth-grade years, students build bridges and birdhouses, learn about manufacturing through toy design, and build and launch their own hot air balloons in addition to a variety of other hands-on design challenges.







gateway to learning

opening the gateway examines how ten school districts in Massachusetts are using technology/engineering as a lens for invigorating learning and teaching in all grade levels. These districts are motivated to meet the standards outlined in the *Massachusetts Science and Technology/Engineering Curriculum Framework*. But beyond that, they understand the value of offering all students—regardless of achievement level or career interests—learning experiences that will prepare them to participate fully in the technological world as professionals and citizens.

The stories included in *opening the gateway* prove that there is no single "right" way for school districts to develop high-quality technology/engineering education programs. On the contrary, every featured district has engineered its own unique strategy for overcoming obstacles along the path to success.

These strategies include:

- Helping elementary school teachers, who may feel intimidated by the discipline of engineering, understand that they may already be meeting many of the state standards.
- Forming coalitions with local businesses and colleges to help find funding and provide brainpower for engineering/technology programs.
- Weighing curricular goals, student needs, and competing financial priorities when developing a technology/engineering facility.
- Bringing engineering instruction to the early grades to inoculate students against race- and gender-based stereotypes about what kinds of people should study engineering.
- Bridging the historical divide between science and technology education departments at the middle school and high school levels to provide hands-on and academically rigorous courses that meet the standards.
- Inviting working engineers into the classroom to demystify the profession and provide students with role models.
- Developing a school culture that encourages students and teachers to fail early and often—and then learn from their mistakes.
- Designing lessons that captivate a range of different learners—and make science and math fun—through hands-on design projects.

These ten districts will continue to participate in the Gateway Project, a Museum of Science program that brings together school district leaders working to implement Massachusetts' technology/engineering standards. During 2006 and 2007, an additional forty school districts will join the Gateway Project community. Through face-to-face and on-line workshops, discussions, and forums, Gateway Project community members will share resources, reflect on practice, and formulate action plans to move their districts further toward the goal of high-quality technology/engineering programs.

For more information about how your district can join the Gateway Project community, contact the Gateway Project co-directors Cary Sneider and Yvonne Spicer at gateway@mos.org or call 617-589-4439.

a shared vision

The National Center for Technological Literacy inspires the next generation of engineers and innovators by leading the nationwide effort to integrate engineering as a new discipline in schools. In addition to providing curricular resources and professional development opportunities to educators, the NCTL serves as a clearinghouse for the most effective strategies for implementing technology/engineering programming district-wide.

The following individuals, foundations, and institutions share our vision for using the classroom to build a technologically literate citizenry. Their generous support makes our formal education programs possible.

Cisco Systems, Inc.
Concord Communications, Inc.
GE Foundation
Hewlett-Packard
Highland Street Connection
Intel Foundation
Lockheed Martin Foundation
Massachusetts Board of Higher Education
Massachusetts Technology Collaborative Renewable Energy Trust
Millipore Foundation
National Institute of Standards and Technology
National Science Foundation
U.S. Institute of Museum and Library Services
U.S. Small Business Administration

clockwise from left: 1. Building electric cars at Doherty Memorial High School in Worcester 2. A student-team design for a prosthetic arm at the Midland Street School in Worcester 3. An engineering workshop for teachers at the Peter Noyes Elementary School in Sudbury