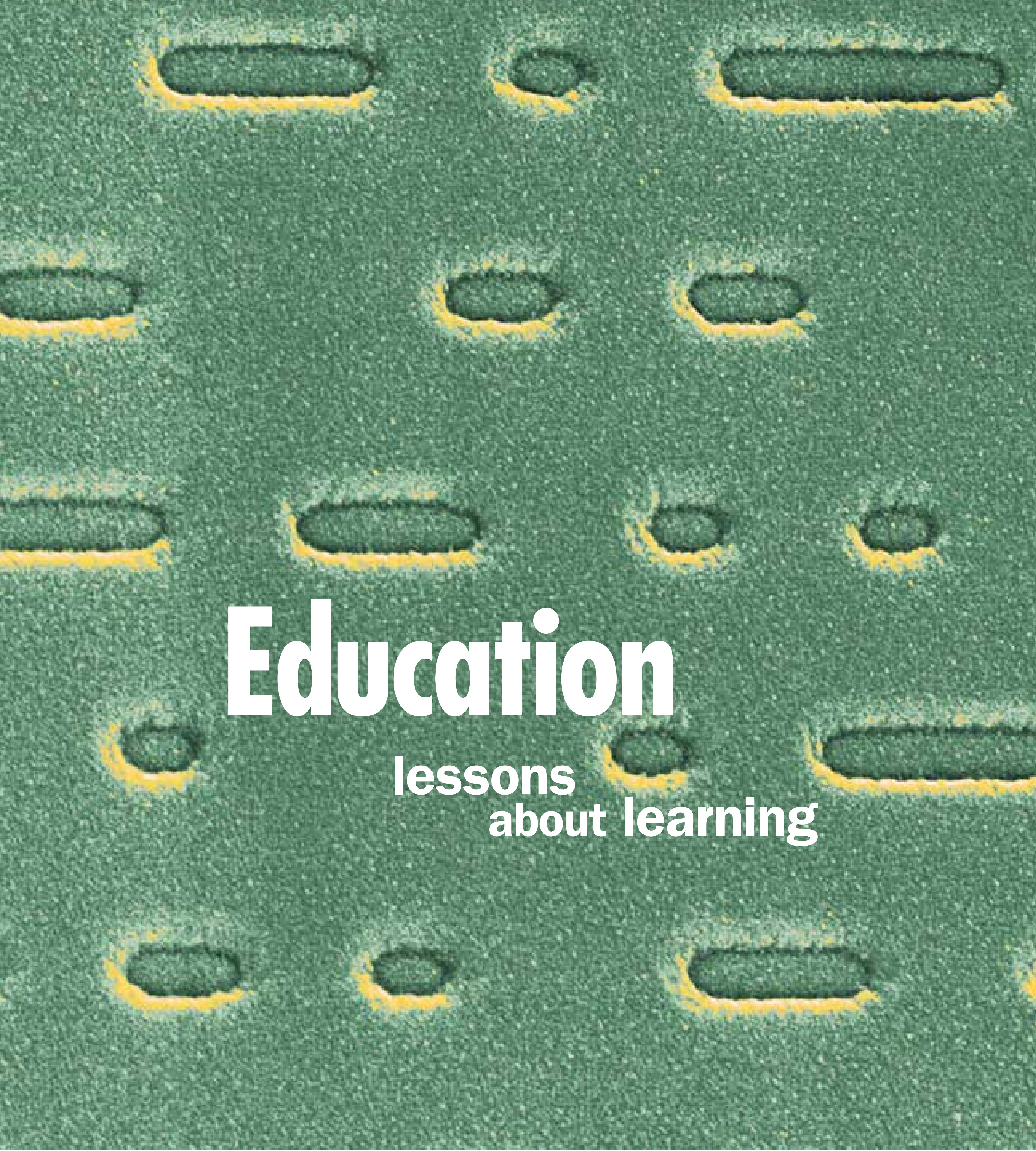
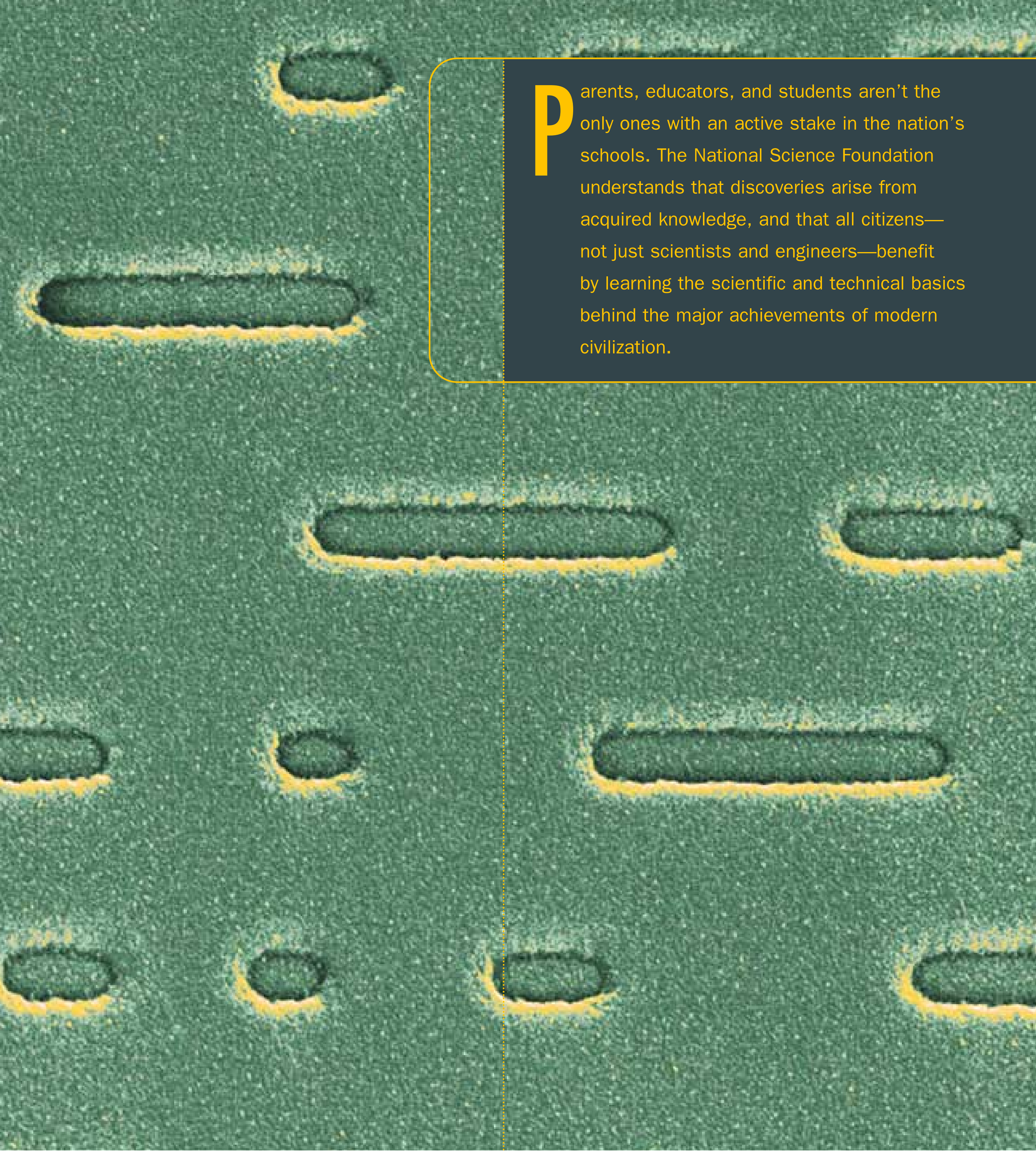


Education

lessons about learning



Parents, educators, and students aren't the only ones with an active stake in the nation's schools. The National Science Foundation understands that discoveries arise from acquired knowledge, and that all citizens—not just scientists and engineers—benefit by learning the scientific and technical basics behind the major achievements of modern civilization.

Education—When it comes to scientific progress, classrooms are just as important as laboratories. That's why nearly 20 percent of NSF's budget is devoted to improving students' grasp of science, mathematics, engineering, and technology—at all levels, pre-kindergarten to postdoctoral. From the agency's Sputnik-inspired reforms of science and mathematics curricula to today's basic research into human acquisition of knowledge, NSF has devoted itself to answering two fundamental questions: How do students learn and what should they know?

The Evolution of Education

Reading, writing, and arithmetic. Rote memorization and drills. American children in the first half of the twentieth century were taught according to the philosophy that the mind was a muscle, which could best be strengthened by lectures and the mental equivalent of push-ups. By the 1950s, critics complained that schools had become little more than vocational sorting stations, sending this child into shop class, that child into family life class, and preparing relatively few for the rigors of college.

All that changed in October 1957 with the Soviet Union's launch into orbit of *Sputnik*, the first-ever artificial satellite. The Russian achievement served as a wake-up call for Americans who realized they needed to improve U.S. science and mathematics education to compete in a science- and technology-driven world. The space race was on, and only a highly educated group of homegrown scientists and engineers could get Americans to the moon ahead of the Russians. For the first time, education in the United States became a major federal imperative.

The government, perceiving a national crisis, turned to the young National Science Foundation, which had established strong ties to the country's research universities. With the National Defense Education Act of 1958, Congress called upon NSF to attend to kindergarten through twelfth-grade (K-12) education in mathematics and science. Later, Congress explicitly added social studies to the mandate.

Over the next twenty years, the Foundation spent $500 million on elementary and secondary school curricula and teacher development. Teams of scientists, educators, and teachers worked together to develop new curricula in physics, biology, chemistry, and mathematics. At the same time, universities held hundreds of summer programs to assist teachers in understanding and using the new materials.

Two aspects of the new curricula distinguished them from their predecessors. First, there was an emphasis on basic principles. How do waves form? What keeps molecules from flying apart? What are functions? Second, there was an assumption that students would best learn basic scientific principles by actually performing experiments rather than simply memorizing facts.

In a 1977 survey, NSF found that 41 percent of the nation's secondary schools were using at least one form of the science curricula developed with NSF funds. In contrast, fewer than 10 percent of schools were using NSF-funded math materials, which many found confusing. Despite the partial success, Congress reined in much of the NSF curriculum effort by the late 1970s. Lawmakers' objections to a new social science curriculum and a general lack of enthusiasm for major changes in education were largely to blame. The decline continued in the early 1980s when the administration's goal of a smaller federal government resulted in budget cuts that hit NSF's education programs particularly hard.

But then the tide turned again. In 1983, a federally commissioned report entitled *A Nation at Risk* warned of "a rising tide of mediocrity" in the nation's schools that was serving to erode America's leadership in the world economy. The report triggered fresh calls for the setting of national or at least state-level education standards and sent NSF back into the K-12 education arena with renewed vigor.

New Approaches for New Times

Today, NSF is once again an influential player in the search for better instructional materials and methods, largely through the efforts of its Directorate for Education and Human Resources. The current programs embody what was learned from the successes and disappointments of earlier years, and also reflect the importance of science and technology to the U.S. economy—and hence, to the country's workforce and citizenry.

A defining feature of today's curriculum reform movement is the emphasis on all students. Regardless of whether they intend to pursue science-related careers or even to go to college, all students should receive quality mathematics and science instruction before they leave high school. And at NSF, "all students" means everyone, including girls and women, persons with disabilities, and ethnic minorities—groups that remain underrepresented in the nation's science and engineering communities.

Of course, what constitutes a good way to learn and teach science and mathematics remains a matter of some debate, as evidenced by the current effort to develop and implement standards. State and local districts now have two sets of national standards to guide them: the 1989 standards put forth by the National Council of Teachers of Mathematics and the 1996 National Science Education Standards established by the National Research Council. Both sets of standards grew out of long processes, including in-depth consultations with the science and mathematics communities, with teachers and educational researchers, and with others concerned about the issue.

NSF-funded curriculum development teams are also drawn from a broad spectrum of the science, mathematics, and educational communities. In their standards-based approaches, these teams are moving beyond the kind of learning-by-doing that asks students to conduct experiments or manipulate mathematical equations with the simple goal of getting an already-determined result—doing things the "right" way to get the "right" answer. In the new "inquiry-based, problem-oriented" curricula, students become participants in discovery by using fact-based knowledge to think through open-ended problems in a variety of ways.

Making Mathematical Connections

Take *Connected Mathematics*, for example, a middle-school instructional series developed in part with NSF funds. In 1999, these materials were being used in more than 2,200 school districts across the country. *Connected Mathematics* was judged the best of four—and only four—sets of middle-school mathematics materials receiving an excellent rating from Project 2061, a curriculum reform effort of the American Association for the Advancement of Science. The three other top-rated instructional materials—*Mathematics in Context*, *MathScape*, and *Middle Grades Math Thematics*—were also developed with NSF funds. None of these materials, however, are as yet in wide use.

What's so different about *Connected Mathematics* and the other top-rated materials? Ask Linda Walker, a teacher at Cobb Middle School in Tallahassee, Florida, who participated in the development of *Connected Mathematics* and whose school district implemented the series with the help of an NSF grant.

"When I went to school," she says, "there was one way to do a mathematics problem—the teacher's way. He'd show you how to work the problem, repeat it, and move on. With *Connected Mathematics*, I set up a problem and then let the kids explore for answers. They gather data, share ideas, look for patterns, make conjectures, develop strategies, and write out arguments to support their reasoning. Instead of getting bored, they're getting excited."

Excellence in Higher Education

The longest running education program offered by the National Science Foundation is the Graduate Research Fellowship, which provides funds and national recognition to university students working toward careers in science or engineering. In 1952, NSF's first fully budgeted year, almost half of the agency's $3.5 million appropriation—$1.5 million—was disbursed in the form of research fellowships to 573 graduate students, 32 of them women.

From the start, awardees considered the NSF fellowships prestigious and career-making. More than one member of the class of 1952 has kept the telegram that brought the news of his or her good fortune. World-famous biologist and Pulitzer Prize-winning author Edward O. Wilson recalls that "the announcements of the first NSF pre-doctoral fellowships fell like a shower of gold on several of my fellow [Harvard] students in the spring of 1952. I was a bit let down because I wasn't amongst them." Wilson's spirits lifted the following Monday when he got his own, albeit belated, notice.

Of the thousands of young scientists who have received fellowships over the years, many have made significant contributions in a wide variety of fields and eighteen have gone on to win Nobel Prizes. Says Donald Holcomb, professor emeritus of physics at Cornell University and a 1952 graduate research fellowship recipient, "I do think it is fair to say that the coincidence of the career spans of me and my contemporaries with the life span of the National Science Foundation created a symbiosis which has profited both us as individuals and American science at large."

Today graduate research fellows—and, in fact, all science and engineering students—have a large number of superior colleges and universities that they can attend, almost anywhere in the United States. But it wasn't always so. NSF's science development programs—better known as the Centers of Excellence—were created in 1964 in response to several national concerns: the growing population of college and university students, the explosion of scientific and engineering knowledge, and the fact that the country's top-notch research schools were concentrated in only a few regions of the country. Through such programs as the University Science Development Grants, the Departmental Science Development Grants, and Special Science Development Grants, NSF helped degree-granting institutions all around the United States strengthen the quality of their science-related research and education activities during the 1960s and 1970s.

"NSF provided the seed money for the development of institution-wide master plans, and also helped to fund the implementation of those plans," says Judith Sunley, NSF interim assistant director for Education and Human Resources. "Then the universities took over, providing the funds to maintain excellence over the long haul."

The first grants were announced by President Lyndon Johnson in 1965. By 1972, when the last science development awards were made, NSF had distributed $233 million in 115 grants to 102 public and private institutions in forty states and the District of Columbia. Institutions used the grants primarily to recruit strong faculties, support postdoctoral scientists and graduate students, acquire sophisticated equipment and materials, and construct, modernize, and renovate laboratories, libraries, and other special facilities for research and teaching.

NSF's Centers of Excellence program resulted in stronger science and engineering departments across the United States. The program's impact continues to be felt by succeeding generations of science and engineering students.

(Information on the graduate research fellows' Class of 1952 is based on material gathered by William A. Blanpied, NSF's Division of International Programs.)

In one recent eighth-grade class, Walker asked her students to redesign a brand-name cereal box to use less cardboard while putting the same amount of cereal in the same number of boxes on a grocery shelf. There was no single right answer—the goal was just to come up with a more environmentally friendly box design and, as a result of the exercise, learn about the ratio of surface area to volume.

Walker says she could have had her students just crunch out formulas, but too much would have been lost in the process. "The importance of a student's exploration is that you, as the teacher, can see what they're *really* understanding," she says. "Getting a correct answer is only one goal. Are they comfortable with fractions or do they avoid them in their calculations? What do their guesses tell you about what they know and don't know?"

Science Instruction Changes Course

As for science courses, among the many inquiry-based curricula developed with NSF funds is *Active Physics*, a course for high school students that creatively organizes physics content. Usually, students study physics in a predictable way: mechanics during the fall term, waves in the winter, then electricity and magnetism in the spring. With *Active Physics*, students explore concepts in one of six thematic areas, such as medicine or sports.

These high school scientists are engaged in a hands-on Active Physics exploration. The Active Physics curriculum, developed with the help of NSF funding, helps students to better understand and appreciate the unseen forces that shape our daily lives.

In one classroom exercise, students draft a mock proposal to NASA under a scenario in which the space agency, as part of its plans for a moon colony, is soliciting ideas for how to encourage exercise among the colonists. The students' challenge is to invent or modify a sport so that colonists can play it in the meager gravity of the moon's environment. As a result, students learn about friction's relationship to weight and discover that there is little friction on the moon. They learn why moon football might put a premium on lifting opponents out of the way rather than trying to push them, and why figure skaters would need larger ice rinks for their quintuple jumps.

"Why don't kids like mathematics and physics but do like English and social science?" asks Arthur Eisenkraft, science coordinator for the Bedford Public Schools in New York. Eisenkraft developed *Active Physics* with NSF funds and the help of leading physicists, physics teachers, and science educators. "At least one reason is that something like *Grapes of Wrath* can spark kids to share their own experience with poverty or hopelessness. They get to contribute to the discussion, really contribute, not just . . ."—raising his hand in imitation of a student with the right answer to a math question—". . . 4.3. With *Active Physics*, students never ask me, 'why are we learning this?' And my AP [Advanced Placement] kids get just as much out of it as my LD [learning disabled] kids."

Most widely used middle and high school science textbooks do not yet reflect these new approaches, though a growing body of evidence suggests that they should. The Third International Mathematics and Science Study (TIMSS), conducted in 1995, involved forty-one countries at three grade levels and compared students' grasp of mathematics and science. U.S. students scored above the international average in both mathematics and science at the fourth-grade level, dropped below average in mathematics at the eighth-grade level, and by twelfth grade were among the worst performers in both science and math. In May 1999, however, a study involving NSF-funded curricula and teacher development efforts showed that they seemed to be making a difference. When given the physics portion of the TIMSS test, students who were learning physics with NSF-supported curricula or from teachers trained in NSF-funded projects posted scores significantly higher than U.S. students in the initial TIMSS assessment.

Curriculum reform is a work in progress. However, even the best reformulated instructional materials won't be enough to sustain real improvement in students' grasp of science and mathematics. Just ask their teachers.

A More Synergistic Whole

In July 1999, Gerry Wheeler, executive director of the National Science Teachers Association (NSTA) and a long-time veteran of the curriculum reform effort, stood before a crowd of teachers gathered to learn about the latest NSF-sponsored K-12 curricula.

"We've been saying the same thing since Sputnik," he exclaimed. "We need inquiry-based curricula, we need to make thinking citizens of our children. But we also need to do more than just produce good material." He pounded the lectern once or twice for emphasis, as if to mark time with the teachers' nodding heads. "What good is the best textbook if teachers aren't given the time, material, and support they need to prepare themselves to use it?"

One of the things NSF learned from its curriculum reform efforts in the 1960s and 1970s was that more needed to be done to prepare teachers to use new materials. Today that means setting up training opportunities that meet not just for a couple of weeks in the summer but also in the evenings or on the weekends, or even over the Internet—whatever best accommodates the teachers' own schedules and far-flung locations. Teachers learn not just about the content of the new curriculum, but also the practical aspects of implementing it. This includes everything from new ways to assess student progress (for example, through students' daily journals) to suggestions for gaining support from parents, colleagues, and school boards. NSF programs also encourage school districts to free up senior teachers already trained in the new curricula to coach others.

Stronger professional development for teachers and improved materials are crucial, but by themselves won't be enough to make a major difference in the way students learn. What's needed is a larger vision that addresses all the factors affecting the success of a student's educational experience. At NSF, a key part of that vision can be summed up in two words: systemic reform.

The idea is simple even if the execution is not—in order for a better set of practices to take hold in a school, everything influencing the school system must be reevaluated, from parental involvement right on up to statewide laws and policies concerning education. NSF launched the Statewide Systemic Initiatives (SSI) program in 1991. In the program's first three years, NSF provided funds to twenty-five states and Puerto Rico to help them start on systemic reform. Today, seven states and Puerto Rico are participating in a second phase of the SSI program. In addition, modified systemic approaches form the basis of the Rural Systemic Initiatives (RSI) and Urban Systemic Initiatives (USI), and the Local Systemic Change (LSC) component of NSF's teacher enhancement programs.

These members of the Wilson High School (Rochester, New York) FAIHM team work on a robotics project. FAIHM, funded in part by NSF, is an acronym for FIRST (For Inspiration and Recognition of Science and Technology), Autodesk, Institute for Women and Technology, Hewlett Packard, and MIT. The program is designed to promote interest in science and technology that will lead high school women to careers in engineering.

In states and territories around the country, NSF's Statewide Systemic Initiatives program is successfully combining curriculum reform—including hands-on activities such as this exhibit at the San Francisco exploratorium for students—and teacher training to improve student performance in science and mathematics.

Through these programs, NSF grants funds to local school systems with well-thought-out plans for how to reform K-12 science and mathematics education at the state, city, or regional level. So far, NSF has spent more than $700 million on such efforts.

How well can systemic reform work? During the 1994-95 school year, the first year that NSF funded the urban systemic program, Chicago's school system saw significantly more of its students score above the national norm in mathematics on a commonly used assessment called the Iowa Tests of Basic Skills. What's more, Chicago students' performance in mathematics has increased in sixty-one out of sixty-two high schools, suggesting that improvement is occurring across the board. Similar results have been achieved in Detroit, where students from a diverse range of public schools performed significantly better on a state standards test after the Detroit Urban Systemic Program implemented sections of the *Connected Mathematics* curriculum. And in Dallas, the number of students passing science and mathematics Advanced Placement tests has tripled since the start of NSF systemic reform funding.

On the state level, Puerto Rico has raised its students' achievement in science and mathematics with an innovative pyramid system that brings systemic reform to one school at a time. The NSF-supported effort, which began in 1992, has so far brought standards-based curricula into more than one-quarter of the island's schools.

"Everybody said it was a clumsy idea because it takes so long," Manuel Gomez, head of the Puerto Rico SSI, told a reporter in 1998. "But I said, 'Be patient. It will work if we give it time.'"

Given the complexities, time is a critical factor to the success of any systemic reform initiative—time, and local school systems willing to commit energy and resources long after NSF's initial support has kick-started reform.

"The underlying belief of systemic reform is that piecemeal attempts, limited by finite projects and inadequate funding, will not change the system, its culture, and its capacity to share what happens in the classroom," says Daryl Chubin, a senior policy officer with the National Science Board, the governing body of NSF. "Change requires conviction and staying power. Nothing happens quickly."

Infusing Education with Research

True reform at the system level requires the participation of everyone who cares about improving the way that students learn about science, mathematics, and engineering. And that includes the research community itself. Finding more ways to foster the infusion of research into education is a major NSF goal as the agency heads into the new millennium.

"If we are to succeed in making our education system truly world class," NSF Director Rita Colwell told the U.S. House of Representatives' science committee in April 1999, "we must better integrate our research portfolio with the education we support."

One way NSF has been taking on this challenge is to fund programs that link ongoing research projects with K-12 students through information technologies such as the Internet. A prime example: the Albatross Project.

Science for Everyone

The good news is that more women and minorities are earning undergraduate and graduate science and engineering degrees—their numbers rose as much as 68 percent from 1985 to 1995, according to recent data from a series of congressionally mandated reports prepared by NSF's Division of Science Resources Studies.

The bad news is that they and persons with disabilities are still underrepresented when compared with the overall U.S. population of eighteen- to thirty-year-olds.

While NSF as a whole is committed to ensuring that the nation's scientific and technical workforce is peopled by all those with gifts to contribute, this mandate is the specific mission of NSF's Division of Human Resource Development, a branch of the Directorate for Education and Human Resources. Why is the crusade for equity allied so closely (though not exclusively) with NSF's educational aims? Because schools are fulcrums on which a young life can turn.

For example, when Tanya Lewis entered Louisiana's Grambling State University (GSU) as a freshman, she signed up to participate in an NSF-funded minority scholars program whose goal was to attract undergraduates to the school's physics and chemistry departments and guide them into graduate school. She struggled with class work and with problems in her personal life; midway through, she decided to take a full semester off. Even then, the mentor who had been assigned to Lewis kept calling.

"I remember sitting in my house and thinking about what it used to be like to get up and go to school everyday and do research," Lewis says. "I realized that I had a gift, and I missed it. I knew I wanted to spend my time doing research."

The next semester, with her mentor's support, she returned to GSU and graduated in 1995. The following fall, she entered graduate school.

Blinded at the age of five in a household accident, Lawrence Scadden, director of NSF's Program for Persons with Disabilities, knows firsthand the frustrations that confront someone bucking society's notion of who should be a scientist.

"For far too long we've been closing disabled people out of science and math," says Scadden, who received his doctorate in psychology and has spent thirty years conducting research in human perception. "These attitudes—the myths and the ignorance—have created a major barrier that must be removed."

Mentors, culturally appropriate role models, networking, quality learning materials, research fellowships, access to skilled teachers and to assistive technologies that can help students overcome impairments—these are the factors included in myriad NSF programs aimed at knocking down barriers of poverty, discrimination, and distrust.

NSF-funded research into new learning technologies, such as the virtual reality demonstration at right, gives students hands-on experience in the scientific process.

Wake Forest University biologist David Anderson is tracking albatrosses that nest on Tern Island, Hawaii, in an effort to understand (among other things) how the availability of food affects the huge seabirds' extremely slow rate of reproduction. The birds embark on searches for food that last days and even weeks. Do the albatrosses simply fly to relatively close feeding sites and, once there, take plenty of time to gather their food? Or do they travel to remote feeding areas, pick up their food, and return immediately? Supported by NSF, Anderson has worked for years to discover why the trips take so long, using satellites to keep tabs on albatrosses fitted with miniature transmitters.

But early in his research Anderson realized that his project had applications beyond the science of albatross behavior. "It's a perfect opportunity to engage school-age kids in science," he says.

So in a collaboration that continues today, Anderson arranges to feed the satellite data via daily emails to middle school classes that sign up for the experiment from all over the United States. Teachers receive software and support material that help them guide their students in making sense of the birds' movements. A related Web site provides even more information, such as weather systems that could affect flight patterns, basic facts about albatross biology, and material on the history and geography of the Northwest Hawaiian Islands. Mathematical techniques to calculate the birds' flight distances and speed are clearly explained. The students then analyze the data in terms of the hypotheses about the birds' food journeys.

"Kids need to know that scientists pose a conjecture, or hypothesis, and then collect data to try to prove or disprove the hypothesis," says Anderson. "This project emphasizes science as a process and a tool to get reliable answers to questions. At the same time, the data help us answer basic questions about declining albatross populations worldwide." So far the project has filled in many details about albatross behavior, including the fact that the birds can fly for hours, and maybe even days, without flapping their wings, thereby conserving energy on long-distance hunts for food.

Another example of how information technologies are allowing students to perform actual research is the NSF-funded Hands On Universe Project, originally developed in 1991 by astrophysicist Carl Pennypacker of the Space Sciences Laboratory at the University of California at Berkeley. As large telescopes became automated, they began generating huge numbers of new images that needed to be analyzed. Pennypacker's idea was to get students involved by providing schools with image processing software, an archive of astronomical images, and related curriculum materials.

In 1995, a couple of astronomy teachers—Hughes Pack of Northfield Mount Hermon School in Northfield, Massachusetts, and Tim Spuck of Oil City Area High School in Oil City, Pennsylvania—teamed up with Jodi Asbell-Clarke of TERC, a nonprofit research and development organization in Cambridge, Massachusetts, to develop a Web-based project that works in conjunction with the Hands On Universe (HOU) curriculum. Their HOU Asteroid Search project allows students to download recent images via the Internet from an NSF-supported telescope in Chile with the specific aim of looking for previously unidentified asteroids. Over the years, students have found nearly two hundred asteroids that appear never to have been seen before in the main belt of asteroids circulating through the solar system.

Then, in 1998, three high school students taking Pack's astronomy class made an even more exciting discovery: a previously unknown asteroid in the Kuiper Belt, a collection of celestial objects orbiting beyond Neptune thought to be leftovers

A Lifelong Love of Science

The Informal Science Education (ISE) program, created in 1984, is one way that NSF nurtures a lifelong love of science. ISE projects include everything from film and radio to exhibits in museums and technology centers. The idea, says Hyman Field, deputy division director of the Elementary, Secondary, and Informal Education Division, is to "engage everybody from pre-kindergartners to senior citizens in activities outside the formal school system."

About a third of ISE-supported projects involve radio, television, or film. Two particularly successful shows are aimed at young audiences. *The Magic School Bus®* began as a series of commercial books published by Scholastic Inc. for children of elementary school age. The series features a wacky science teacher named Ms. Frizzle who takes her class on educational field trips in her magically transformable bus. "Building on [the books]," says Field, "we supported development of a television series—one of the first animated series on the Public Broadcasting System for early elementary school kids."

The television exposure stimulated fresh outlets for the project. A live, traveling version of *The Magic School Bus®* now brings fun science activities to schools, malls, and theaters. Related materials, such as videos, CD-ROMs, and teaching guides are also available.

Older children have benefited from the televised exploits of Bill Nye, the Science Guy. A mechanical engineer who moonlighted as a stand-up comic, Nye first appeared as the Science Guy in 1987 on *Almost Live!*, a local version of *Saturday Night Live* in Seattle. Six years later, Nye and two producers had expanded the concept into the outline of a popular science show featuring Nye's zany but educational demonstrations using inexpensive, safe household items. As with *The Magic School Bus®*, NSF provided the initial funding that has allowed the Science Guy to take off and succeed.

Programs such as Teachers Experiencing Antarctica combine research and education in an effort to improve both teacher training and student appreciation and mastery of science, math, engineering, and technology.

from the formation of the solar system. At the time of discovery, only about seventy-two such objects had been identified—none, until that point, by anyone other than a professional astronomer. The students—Heather McCurdy, Miriam Gustafson, and George Peterson—had become stargazers of the first order.

"They called me over to take a look at a couple of dots on an image they were analyzing," recalls Pack of that October afternoon. "They suspected the dots were artifacts, and I agreed with them. But right below those dots was another pair of dots that made the hair on the back of my neck stand up. I recognized the signature of Kuiper Belt objects. But I was a good teacher and just took a deep breath and turned to walk away. Then one of the girls said, 'Mr. Pack, what about *these*?' They told me the dots looked like evidence of an object that was moving, and at a very great distance."

A week later, with the help of their cohorts in Oil City, the Northfield students had done all the calculations needed to confirm their find.

Says HOU founder Carl Pennypacker, "This is a fantastic piece of science, of education, of discovery. The Northfield students' discovery has shown that all students from a broad range of backgrounds can make solid, exciting, and inspiring scientific contributions."

Students aren't the only ones to benefit from direct experience with scientific research. NSF sponsors a number of programs that temporarily put K-12 teachers "in the field," with or without their students, while also coaching the teachers on how to transfer their research experience into classroom learning. As a result, NSF-sponsored teachers are working alongside scientists in the forests of Puerto Rico and the floodplains of the Mississippi Delta, at Washington State's Pacific National Laboratory and West Virginia's National Radio Astronomy Observatory. Some are even going to the ends of the Earth itself.

Each year the Teachers Experiencing Antarctica and the Arctic (TEA) program sends between eight and twelve elementary and secondary teachers to research stations at or near the polar ice caps for up to eight weeks. TEA teachers have explored hydrothermal vents around the Antarctic Peninsula, pulled ice cores from the Greenland Ice Sheet, and released weather balloons at South Pole Station. Professional support abounds, both before and after the research trips. Veterans from past TEA expeditions help mentor the new recruits, who also spend time at the home institutions of their scientist-partners where they get a thorough grounding in their particular project. During their expedition or upon their return from the ice, TEA teachers receive professional help in turning their experience into classroom lessons, sharing their knowledge with other teachers back home, and even attending scientific conferences as co-presenters with other members of the polar learning community.

In 1998, as a biology teacher at Mayo High School in Rochester, Minnesota, Elissa Elliott joined a team of researchers studying microbial life at frozen Lake Bonney in the Dry Valleys region of Antarctica. She kept a daily journal, as TEA teachers are encouraged to do, and uploaded her entries along with photos to the TEA Web site maintained by Rice University. That way, her students back in Minnesota could share in her learning and excitement. Elliott was in electronic contact with more than three hundred classrooms and individuals interested in learning about Antarctic science in real time.

A New Formula for Calculus

By the 1960s, three hundred years after Gottfried Leibnitz and Isaac Newton independently developed it, calculus had become a standard freshman course for students in the physical sciences and engineering. Faculty began to use grades in those courses to screen potential majors in other scientific disciplines and to weed out the less gifted students, even in majors that scarcely required calculus. That approach drew protests, particularly from students not destined for fields that required advanced training in mathematics. The fact that several colleges took an assembly line approach to the subject, grouping students in large lecture classes taught by teaching assistants, exacerbated the situation. Indeed, a high proportion of the more than half a million students enrolled in calculus courses each semester either failed or could not apply calculus concepts in later courses.

In January 1986, mathematicians from twenty-five influential colleges and universities met at Tulane University under the auspices of the Mathematics Association of America (MAA). There, they discussed better ways to give students a conceptual grasp of calculus. NSF kept in touch with the reform movement, and in October 1987 announced its Calculus Curriculum Development Program, jointly administered by the Divisions of Undergraduate Education and Mathematical Sciences.

Over the next ten years, NSF-supported reform projects eventually led to a significant change in how calculus was taught. Changes include the use of graphing calculators and computers, open-ended projects, extensive writing, more applications, and use of cooperative learning groups. NSF-funded projects have also changed the infrastructure of calculus teaching. Virtually every traditional college-level textbook has been revised in light of the reform movement. The Advanced Placement calculus outline for high school students has been overhauled, and revisions are underway on the Graduate Record Examination's mathematics section.

"There is no question of the importance the NSF initiative has had in achieving the changes reported to date," wrote the authors of an MAA report. "The NSF program successfully directed the mathematics community to address the task of reforming the calculus curriculum and provided coherence to those efforts."

A substitute teacher was filling in for Elliott during her absence but, thanks to TEA's technical support, "essentially, I was able to hold class from Antarctica," she says. "My students and I emailed back and forth. They had a ton of questions. So much of the time, we're teaching what is already known and the sense of discovery just isn't there. But because I was able to pretty much communicate with them in real time, they could see that science is something that is happening right now. And that does so much more for kids than textbooks do."

A Revolution in University Culture

As exciting and worthwhile as such programs are, of course, they reach only a small fraction of the teacher workforce. Recognizing that not all teachers can go to the field, NSF is looking for more ways to bring the field to them. One approach is NSF's Graduate Teaching Fellows in K-12 Education program. Begun in 1999, the program aims to place graduate and advanced undergraduate science, mathematics, and engineering students into K-12 classrooms as resources for teachers and students.

A critical component of the fellowship is pedagogical training for the upper-level science students, so they will know how to transform their cutting-edge knowledge into something that younger students can understand and appreciate. Still, "the intention is not to make teachers out of scientists, although some may decide that's what they want to do," says NSF's Dorothy Stout, who headed up development of the program. Rather, NSF hopes that the teaching fellows will go on to become scientists who, in turn, will act as bridges between the research and education communities by serving as resources for their local school districts.

"We want them to be well-rounded individuals," says Stout, "who can enhance K-12 classrooms with their specialized backgrounds."

Or as NSF Director Rita Colwell says, "We cannot expect the task of science and math education to be the responsibility solely of K-12 teachers while scientists, engineers, and graduate students remain busy in their universities and laboratories."

A natural extension of NSF's commitment to bringing the research and education communities together is a greater emphasis on the conduct of research into education itself. Says Colwell, "We've spent a lot of time focused on teaching and yet we don't really know how people learn—how effectively a person's learning can be enhanced, and the differences in how people learn."

Education research emerged as a field in the 1950s and 1960s. Although it once struggled to gain the level of funding and respect afforded to other areas of scientific inquiry, the field is coming into its own as growing numbers of scientists and educators advocate research to better understand how people learn and think.

Finding out more about how children learn, and figuring out how to implement what *is* known about the acquisition of knowledge, are huge challenges. Recognizing the importance of this work, the U.S. government announced in April 1999 a unique collaboration among NSF, the National Institutes of Health, and the Department of Education. The goals of the new Interagency Education Research Initiative (IERI) are to meld different kinds of research in how children learn mathematics, science, and reading; to understand the implications of research for the education community, speeding the implementation of research-based instruction; and to expand the appropriate uses of technology in schools.

For example, one project funded by IERI will conduct a cross-cultural study comparing the early development of mathematical concepts and understanding in three- to six-year-old Chinese, Japanese, and American children. The project will also study how different cultures support the children's early mathematical development in various settings: at home, in child care facilities, and in preschool. The idea is to gain insight into how best to support the growth of children's mathematical skills prior to elementary school.

Another project funded by IERI will expand the testing of an automated reading tutor for at-risk children. Children read aloud while a computer program "listens" and verbally corrects any mistakes. The program is not fooled by accents and is able to use other cues (thanks to a camera mounted on the computer) to see if the child is paying attention to the task. Preliminary studies have shown that seriously underperforming first- and second-graders who use the automated tutor for three to six months jump almost to their grade level in reading skill. Researchers will also compare the automated tutor to human tutors. It's expected that students will respond best to human tutors, but by how much? With schools struggling to provide at-risk students with the extra help they need, such technology could be an affordable and effective boon.

A Great Deal of Good

Since 1950, NSF has worked for stronger curricula and enhanced professional development for teachers. The agency has planted the seeds of systemic change and made it possible for researchers to work in partnership with educators to bolster the scientific basis of learning. Despite all that NSF has done over the years in these areas, some may be surprised to discover just how important education is at one of the country's primary sources of research funding. But NSF's commitment to the nation's students has been part of its mission from the very beginning.

In 1954 Daniel Lednicer, a doctoral student in chemistry, received a third year of financial support through NSF's fledgling Graduate Research Fellowship program. Full of gratitude for the life of learning that NSF was allowing him to pursue (he went on to make important contributions as a research chemist at the National Cancer Institute), Lednicer wrote a letter of thanks to the man who had signed NSF into existence, President Harry Truman. Truman's plain-spoken reply on October 2, 1954, speaks presciently about NSF's unique role as a catalyst for scientific knowledge, in the laboratory as well as in the classroom:

Dear Mr. Lednicer:

Your good letter of September 21 was very much appreciated. I always knew that the [National] Science Foundation would do a great amount of good for the country and for the world. It took a terrific fight and three years to get it through Congress, and some smart fellows who thought they knew more than the President of the United States tried to fix it so it would not work.

It is a great pleasure to hear that it is working and I know it will grow into one of our greatest educational foundations.

Sincerely Yours,
Harry S Truman

To Learn More

NSF Directorate for Education and Human Resources
www.ehr.nsf.gov

American Association for the Advancement of Science Project 2061
www.project2061.org

National Academy Press
www.nap.edu

National Council of Teachers of Mathematics
www.nctm.org

National Science Teachers Association
www.nsta.org

The Albatross Project (at Wake Forest University)
www.wfu.edu/albatross

The Hands On Universe Project (at Lawrence Berkeley National Laboratory)
http://hou.lbl.gov

Teachers Experiencing the Antarctica and the Arctic (at Rice University)
http://tea.rice.edu