K–12 science education reform—a primer for scientists

The nearly concurrent release of the disappointing results of US student performance in the Third International Mathematics and Science Study (TIMSS; NCES 1996, 1998) and the *National Science Education Standards* (National Research Council [NRC] Standards; NRC 1996) has refocused public attention on current deficiencies in science education for US students and possible solutions for its improvement. Reports resulting from TIMSS, a 5-year international project comparing curricula and achievement in 50 countries, ranked twelfth-grade US student performance among the lowest of participating countries in general knowledge of mathematics and science and more specific knowledge of physics and advanced math (NCES 1998). However, at the same time a new vision of science education for K–12 students has emerged. This vision, which calls for excellence in science education for all children, is expressed in the NRC Standards, which, along with Project 2061's *Benchmarks for Science Literacy* (AAAS 1993), provides recommendations and guidelines for student learning, classroom practices, teacher professional development, and overall organization of educational systems.

Development, writing, and review of the NRC Standards involved more than 18,000 people over a 4-year period, including classroom teachers, science educators, engineers, scientists from a variety of disciplines, and representatives from 22 science education and scientific organizations (NRC 1997). NRC Standards are voluntary, yet they are being adapted and applied by local school districts throughout the country, as well as by state educational organizations responsible for creating or implementing educational guidelines. The NRC Standards clearly identifies the need for ongoing partnerships among scientists, teacher educators, teachers, and school districts as a way to address shortcomings in the nation's current approaches to science education.

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Although such partnerships can take many forms, it is almost universally accepted that K–12 science education improves when scientists contribute their knowledge and skills (Wheeler 1998). For most scientists, the world of K–12 education is long forgotten, left in a distant past before years of advanced study. Even scientists with children sometimes find the K–12 culture of teaching and learning—with its own vocabulary, policies, and procedures—difficult to enter and navigate. In addition, members of the science community can unintentionally intimidate teachers and nonscientists and, at the same time, ignore the realities and challenges facing science education today.

A useful beginning step toward enhancing the ability of scientists to work with teachers and schools is to promote basic understanding of the issues by all participants. Scientists, teachers, school administrators, and parents all need to recognize the contributions that each of them can make and be able to talk about their potential contributions using a common language. Mutual understanding of key concepts, approaches, strengths, weaknesses, and barriers is especially important in helping all parties to communicate clearly and work together in meaningful ways.

Many scientists now active in science education reform have discovered that this growing field has developed its own vocabulary—borrowed from both science and traditional education. Simple words and phrases, such as "assessment," "cooperative learning," and "inquiry," have come to identify key concepts related to the ways in which science is taught and how that teaching is supported. Becoming informed—the first step toward participation in school-based science education—requires that scientists develop a working understanding of issues that are facing teachers, students, parents, and administrators. In this article, I provide a brief introduction to basic issues in an attempt to facilitate initial dialogue and encourage eventual collaboration between scientists and their local schools. The discussion is meant to provide a starting point for further exploration and communication, rather than a comprehensive review of the topic.

Teaching strategies that promote scientific literacy

Scientifically literate people, according to the NRC Standards and the American Association for the Advancement of Science (AAAS) Benchmarks, are able to experience the richness and excitement of knowing about and understanding the natural world; to apply scientific processes and principles in making personal decisions; to engage in public discourse about matters related to science and technology; and to increase their economic productivity through the use of scientifically related knowledge, understanding, and skills (AAAS 1993, NRC 1996). Students who are scientifically literate should be able to describe, explain, and predict natural phenomena while understanding that science is an ongoing process focused on generating and organizing knowledge (Uno and Bybee 1994).

Both the NRC Standards and the AAAS Benchmarks provide guidelines for what students should know and be able to do as they progress through grades K–12. The guidelines emphasize the importance of helping students develop a base of knowledge and skills that will continue to grow throughout their lifetimes. Some states and local districts are adjusting or rewriting their guidelines for science education to make them more consistent with the recommendations of one or both of these national projects. In addition, many innovative curriculum development groups have created, or are in the process of creating, instructional programs that help students and teachers meet the NRC Standards by focusing on approaches that develop students' problem-solving and critical-thinking skills. These approaches, which are particularly relevant to "how" students should learn science, include inquiry, cooperative learning, questioning strategies, less-is-more, and real-world relevance.

Inquiry. Current science education reform approaches stress active learning by students. Students are expected to ask questions, acquire knowledge, construct and test explanations, and communicate their ideas with others (NRC 1996). This expectation reflects a change from earlier science instructional models, in which students "did" activities but were not necessarily engaged in solving problems or applying new knowledge. Typically, science laboratory activities would merely confirm or demonstrate concepts that had already been presented to students. Approaches to teaching science that are now being recommended go beyond "hands-on" activities to encourage students to develop thinking skills, values, and attitudes that will be useful throughout their lives regardless of their career choices (AAAS 1993). The phrase "hands-on, minds-on" is frequently used to distinguish this approach from mere hands-on instruction.

More formally, the idea of inquiry-based learning is expressed as the "learning cycle," a three-phase instructional model originally proposed by Karplus and Thier (1967). During the exploration phase, students are presented with and allowed to explore a problem or discrepant event that challenges their existing knowledge. Nothing is solved during this information-gathering phase, but students may produce hypotheses to explain the observations. During the "invention," or concept introduction, phase, students use evidence gathered through exploration to integrate their hypotheses with prior knowledge and construct new concepts. Finally, in the "discovery," or concept application, phase, students apply their newly constructed knowledge to a novel situation (Allard and Barman 1994, Marek and Cavallo 1997).

The term "inquiry" is used in the NRC Standards not only to refer to teaching methods in which students construct their own knowledge by doing, but also to designate specific characteristics of scientific processes that students should be able to understand (Hackett 1998). Thus, content standards for "Science as Inquiry" include the development of abilities (e.g., how to identify questions, how to design and conduct scientific investigations, how to use technology and mathematics) and understanding (e.g., scientists conduct investigations for a number of reasons, mathematics is an essential tool of science, and scientific explanations must adhere to certain criteria).

Another component of inquiry is the notion that inquiry-based instruction should be designed to reflect children's cognitive development (Lowery 1990). In other words, instruction should be "age appropriate." This realization has resulted in a re-ordering, by the NRC Standards, of the recommended sequence of science topics and skills experienced by precollege students. In life sciences, for example, students in grades K–4 are expected to understand characteristics of organisms (e.g., basic needs, structures and functions, behavior); life cycles of plants and animals, including rudimentary concepts of inheritance (e.g., "plants and animals closely resemble their parents"); and relationships of organisms to their environments (e.g., food webs, environmental change). The focus in grades 5–8 shifts from learning about individual organisms to recognizing patterns and understanding cells and microorganisms. This work, in turn, provides a foundation for the understanding, in grades 9–12, of molecular processes in living organisms; biological evolution; and matter, energy, and organization in living systems.

Cooperative learning. Most effective inquiry-based science instructional programs organize students into groups in which each individual is responsible for defined tasks or content areas. This approach, known as cooperative learning, is believed to bring important benefits to students, including enhanced individual learning, greater retention of knowledge, improved development of social skills, and more opportunities for students with a wide range of abilities to make important contributions to the group (Cohen et al. 1995, Herreid 1998). Cooperative groups typically have four or fewer students and are heterogeneous with respect to academic achievement, gender, and ethnicity (Slavin 1995). Students have specific roles, which are rotated among group members. In elementary school, for example, these roles might be "principal investigator," "recorder–reporter," "materials manager," and "maintenance director" (see Table 1). For teachers to implement these techniques in their own classrooms, they should ideally have opportunities to experience cooperative learning firsthand, either as undergraduate students or through in-service professional development opportunities.

Questioning strategies. Inquiry-based science instruction requires classroom teachers to reshape their relationships to students. Teachers become facilitators who provide encouragement and guidance, instead of deliverers of information through lectures or assigned readings. This transition implies that teachers give up their roles as experts and allow students to learn through their own collaborative explorations. Once they have begun to change their strategies, some teachers, particularly those in elementary school, find the notion of becoming facilitators liberating. They feel more free to discover and question along with their students and develop confidence in their own abilities as teachers of science. As one elementary school teacher noted, "I have become a scientist, involving my students in numerous experiments, discoveries, demonstrations, etc. My students are more observant and inquisitive" (as told to Marsha Lakes Matyas, American Physiological Society, Washington, DC, personal communication).

Thoughtful questions can best help develop students' understanding when posed in positive ways. Encouraging questions can be framed as "Have you seen?" "How many?" "Did you notice?" "What happens if?" and "Can you find a way?" Questions of this type help students learn to observe carefully, make predictions, and connect variables (Elstgeest 1985) and are, therefore, usually more productive than questions that stress a single right answer. An important component of this strategy is having the patience to wait more than a few seconds for students to respond. Allowing 8–10 seconds of "wait time" before requiring a response encourages class participation by more students and often promotes more thoughtful and creative responses (Carin and Sund 1989). Teachers can develop appropriate questioning techniques by participating in professional development programs. Coaching and mentoring strategies are also helpful for new teachers or for experienced teachers who want to develop a new approach to science teaching (Stiles and Loucks-Horsley 1998).

Less-is-more. The science curriculum in most US schools attempts to cover many more topics per year than the international average. Described as "a mile wide and an inch deep" (Schmidt et al. 1996), the current approach to science teaching has been identified as contributing to the recent poor showing by US students in science and mathematics, as noted earlier (Vogel 1996). Commercially published textbooks may also contribute to the lack of depth. Science textbooks, which are designed to be appropriate for as many school districts as possible, frequently touch on more content areas than can be taught within an academic year and cover many concepts only superficially. Many educators believe that students would be better served by instructional programs that examine fewer topics in greater depth. This less-is-more approach emphasizes understanding concepts instead of memorizing facts and vocabulary and allows students to apply and extend science learning to their daily lives (Pratt 1998).

Table 1. Typical job assignments for student cooperative groups in elementary school.[a]

Job title	Task[b]
Principal investigator	Reads the directions; asks the questions; checks the work
Recorder–reporter	Writes down the observations; reports the results and new questions; tells the teacher when the group is finished
Materials manager	Picks up the materials and equipment (from a central location); uses the materials and equipment; returns the materials and equipment; asks others to help with use of the equipment
Maintenance director	Makes sure the group follows the safety rules; directs the clean-up; asks others to help with clean-up

[a]Adapted from Jones (1990).
[b]Tasks are usually rotated within each group for different activities so that each student has an opportunity to experience all roles.

The idea of emphasizing depth rather than breadth is leading to the creation of science learning programs by both nonprofit groups and commercial publishers that are different from traditional textbooks and their accompanying science "experiments," which merely confirm or demonstrate concepts that students have already learned. For example, in the elementary grades new inquiry-based programs may cover only four to six major topics per year. Students conduct a series of carefully ordered activities that allow them to gradually discover important science concepts and to apply their knowledge to new situations. In one program (NSRC 1998), students in third grade might explore plant growth, development, and nutrition using Wisconsin Fast Plants™; differences and similarities among rocks and minerals by applying physical and chemical tests; chemical properties of materials by investigating common household chemicals (such as sugar and baking soda); and sound creation and transmission. Some districts and schools are even combining instructional units from more than one source to create a customized program of studies that meets specific state or local guidelines for each grade level.

Implementation of instructional programs covering fewer topics in greater depth over the course of a school year sometimes faces opposition from teachers or parents. Teachers often have considerable personal investment in the programs they are teaching. In many cases, teachers have developed individual expertise in topical areas that they have covered for many years. In addition, teachers frequently adapt and refine their own units over time, leading to personal "ownership" of particular topics and activities. Introduction of new instructional programs may force teachers to teach outside their areas of self-developed expertise or experience or to abandon personally developed units that they view as successful. Strong professional development programs are effective in helping teachers become successful advocates of new programs.

Some parents may criticize programs that explore four to six "big" themes per year as lacking rigor because these programs are not based on a thick textbook. Other parents will insist on seeing traditional classroom products, such as worksheets and quizzes. Some schools and school districts have found that obtaining early support from parent organizations greatly facilitates the transition from traditional to inquiry-centered science programs (NSRC 1997). Letters to parents, sent home before beginning a new program of instruction, also help promote understanding and shape expectations.

Real-world relevance. Current reform efforts stress the need for students to learn to connect the science learning that happens in school to their own experiences. This emphasis represents a reaction to textbook- and lecture-based instruction, in which students are taught facts and terminology but not knowledge and skills that can be applied in everyday situations. The abilities to use scientific information, to think critically, and to solve problems related to the natural and man-made worlds are valuable habits of mind that contribute to both individual and societal well-being. These abilities can, for example, influence choices related to medical treatment, help children and others assess risks associated with any number of behaviors and actions, and promote informed participation in government. As noted by Maienschein et al. (1998), "we must have a society rich in both critical, creative scientific thinkers and enough knowledgeable experts to do today's work."

Teachers, parents, and other educators can help students link their science experiences in school to the world outside the classroom by connecting science to other school subjects, such as mathematics and language arts; by placing more emphasis on understanding scientific concepts, rather than knowing facts and information; and by applying the results of experimentation to new arguments and explanations (NRC 1998). The payoff of such an approach is often increased student interest and motivation to learn science.

Opportunities for all students

Inherent in the NRC Standards is the concept that all children can and should have excellent and equivalent science learning opportunities. While acknowledging that not all students will pursue advanced studies in science and mathematics, the NRC Standards emphasizes that all students should develop the fundamental knowledge and skills necessary for functioning in a world filled with the products of scientific inquiry (NRC 1996). The emphasis on science literacy for all children represents a fundamental shift from the goals of the science education movements of the 1960s and 1970s, which were specifically intended to produce more scientists and engineers (Bybee 1997). The current challenge, which is to reach all children and all schools, raises two related issues: equity of access and materials management.

Equity of access. When "equity" is mentioned as a science education issue, the first thing to come to mind is usually ethnic- or gender-based inequalities in success in science careers. And, as noted by the National Science Foundation (NSF 1999), although the participation of women and minorities in science and engineering higher education continues to increase, this involvement is not yet equivalent to their representation in the 18–30-year-old US population. Throughout grades K–12 and even in college, factors such as a lack of culturally appropriate role models, insufficient parental involvement in school activities, and parents and teachers who do not encourage achievement in science and mathematics all contribute to the problem.

Also affecting these and many other students, however, is the underlying issue of access to skilled teachers, quality learning materials, and adequate time in the classroom—regardless of physical or learning disabilities, socioeconomic status, or geographic location. Inequalities of this nature directly affect K–12 students' experiences and achievement on a daily basis. For example, communities of low socioeconomic status frequently have schools that can be categorized as ineffective, based on qualitative differences in student activities, classroom practices, and school resources and direction (Snow et al. 1998). Findings from the National Assessment of Educational Progress, the nation's only ongoing survey of educational progress (O'Sullivan et al. 1997), also report higher levels of student performance in science among populations with higher levels of parental education, by white and Asian/Pacific Islander students, and by students not participating in Title I programs (a federal program that provides funding to schools serving students at risk of school failure who live in low-income communities).

"Science standards for all children" (NRC 1996) implies addressing these patterns of opportunity and achievement through distribution of quality resources, teacher training, and student opportunities across all classrooms and schools. In addition, specific classroom management and instructional techniques, such as those mentioned earlier in this article, encourage successful participation in science learning activities by students of diverse backgrounds.

Materials management. Lack of appropriate supplies and equipment for science classes is a significant problem that limits the quality of students' hands-on experiences throughout grades K–12. The problem is most notable in elementary schools, where, in some cases, teachers and students do not have access to even the most rudimentary tools and materials necessary for teaching and learning science. Simple objects, such as rulers, magnifiers, cotton balls, or balances, may not be available in sufficient quantities for an entire class to engage in inquiry-based science activities. Marked differences in the availability of supplies and materials from school to school or district to district create gross inequities in the quality of different science instructional programs. In many cases, particularly in elementary schools, motivated teachers shop on their own time with personal funds to purchase supplies for science lessons. As noted by the National Science Resources Center (NSRC 1997), this "solution" is neither realistic nor efficient.

Much more desirable is centralized management of science materials by schools or districts. Some localities with well-established science programs for grades K–8 provide teachers with kits containing all the science materials necessary for a 3–9 week unit. Kits are purchased from manufacturers or assembled at a centralized location within the school district. School or district science centers are also responsible for refurbishing used kits so that they may be distributed and reused several times during each school year (Lapp 1980). Centralized management and distribution of supplies help to ensure that all students have equally rich science experiences.

Student assessment in science

Traditionally, science learning by students in the classroom has been measured using pencil and paper tests. These tests take a variety of forms and serve numerous purposes within the educational system: Teachers use tests to evaluate the progress of individuals in a particular subject area; schools use tests to evaluate teacher performance; districts use tests to assess the effectiveness of administrators and schools; and state education departments use tests to compare school districts and evaluate progress within the state as a whole. However, many educators believe that even the most carefully designed written tests do not adequately judge students' development of skills (both higher-order thinking skills, such as interpreting data and drawing conclusions, and physical skills, such as observing and measuring), nor do they equitably measure students' abilities to apply content knowledge.

Standardized tests. The use of standardized multiple-choice tests of student learning to judge the effectiveness of local programs, teachers, or administrators affects science education reform in several ways. First, when "science" is not one of the subject areas on which accountability is based, real class time allotted to science instruction may be drastically reduced. In Texas elementary schools, for example, the subjects on the statewide standardized test (currently reading, writing, and mathematics) drive curricula and budgets. In addition, administrators and teachers often perceive a direct and compelling need to "teach to the test" by drilling students on topics and skills that will appear on standardized examinations. One way to ensure that science is included in the curriculum is to help teachers understand the connections of science to other subject areas, such as mathematics and language arts, and how to make those connections on a daily basis.

A related problem can occur when new science instructional programs are not perceived to match state science education guidelines and corresponding mandated examinations. In such cases, teachers and administrators may be reluctant to devote time to teaching programs that, however exemplary, do not cover specific topics that appear on the tests. This situation should change gradually as individual states and school districts continue to align their guidelines more closely to the NRC Standards and generate corresponding standardized tests. It appears unlikely, however, that standardized tests will disappear any time soon. To the contrary, the trend is toward increased use of such instruments by states and national organizations for evaluating and comparing student progress.

Alternative ways to assess student learning. Ideally, assessment—defined broadly as "using any possible means to make judgments about what students have learned" (Hein and Price 1994)—can take many forms. The NRC Standards emphasize multiple approaches to evaluating student learning rather than the exclusive use of traditional worksheets, quizzes, and tests. Alternative approaches can include observing and talking to students, making tape recordings or photographs of students in action, and collecting drawn or written products, including science journals and portfolios. Methods such as these are often referred to as active, authentic, alternative, or performance-based assessments (with subtle differences in emphasis). Most inquiry-based instructional programs, especially for grades K–8, incorporate several different assessment strategies into each thematic unit.

Teacher education

Teacher professional development is viewed by many educators as the most critical and complex variable in the science education reform movement (Moore 1997, Wheeler 1998). As noted in the NRC Standards (1996), "since the current reform effort requires a substantive change in how science is taught, an equally substantive change is needed in professional development practices." Many teachers, particularly those in elementary schools, avoid teaching science or stick to the textbook because they lack experience in a subject area and have little confidence in their abilities to teach it (NSF 1997a).

Teachers' needs for professional development in science are not always met by existing offerings. Preservice (undergraduate) teacher education programs do not necessarily require hard science or mathematics course work, particularly of future elementary-level teachers. As a result, many elementary school teachers graduate without even a rudimentary education in science and mathematics (Rutherford and Ahlgren 1989). Students planning to become secondary school science teachers typically do graduate with significant amounts of coursework in one or more science areas. However, these instructors may find themselves teaching outside their areas of primary science expertise after a few years. Because of changes in school and district enrollments, last year's biology teacher may become this year's additional earth science instructor.

The National Board for Professional Teaching Standards (NBPTS) has created a comprehensive assessment process leading to National Board Certification in science, among other subject areas, for practicing teachers. Currently, certification is available only for teachers at the high-school level (students 14–18+ years old). Certification guidelines in science are under development for those who teach children of ages 7–15 years. National board–certified teachers demonstrate high levels of knowledge and skills as evidenced through a two-part assessment process that includes development of a portfolio at the teacher's school and an evaluation at a centralized location (NBPTS 1999). The National Science Teachers Association (NSTA) has also created a plan for a science Teacher Certification Program, which currently is being reviewed. NSTA teacher certification has the potential to improve the quality of science teaching by recognizing well-qualified teachers and providing benchmarks against which to measure undergraduate and graduate teacher training programs (NSTA 1999).

Teachers' preservice education is frequently distinguished from the professional development of practicing teachers, known as in-service education. Practicing teachers face several barriers in accessing adequate professional development programs in science. Obstacles include a lack of funding, a shortage of time to participate in any kind of training, and numerous competing demands on the limited time that is available. Lack of funding affects the number and quality of in-house programs that schools can make available to teachers; it also affects teachers' abilities to attend outside training opportunities that require tuition. Moreover, for teachers to attend courses during the work week, a substitute teacher must be hired to cover the absent teacher's class. "Who will pay for 'release time'?" is a common question when teachers are invited to take part in training opportunities that fall on scheduled school days.

The issue of release time is also related to the second obstacle—shortage of available time to participate in workshops or courses. Unlike many professionals, teachers are frequently expected to participate in job-related training on their own time (evenings, weekends, or summers) without compensation. Because of budgetary constraints, most schools are also unable to schedule large blocks of time for team planning or professional development. The final obstacle, competing requirements for other training, reflects the numerous demands on the educational system. Most districts only have a limited number of days each year dedicated to teacher development activities. Thus, it is difficult to meet the training needs of a diverse array of teachers.

The NRC Standards provides guidelines for teachers' professional development, recognizing that practicing teachers "will be the representatives of the science community in their classrooms." Ideally, teachers should have opportunities to learn science content and inquiry-based teaching strategies in collegial environments that allow for the sharing of knowledge, that encourage them to connect their learning directly to the context of their own classrooms, and that help them integrate technology and mathematics with science (Darling-Hammond and McLaughlin 1995, Moreno et al. 1997). Teachers should also have opportunities to experience new hands-on teaching programs, but such in-service opportunities—which optimally should be several days or weeks in duration, with follow-up for at least one school year—are not always available, for the reasons already described.

Systemic reform of science education

Ongoing efforts to change the way science is taught in schools focus on all aspects of the educational system. NSF (1997a) describes the systemic approach to science education reform as "a wide-angle view of school change that sees all aspects of the system as a whole." Systemic reform of science education involves simultaneously addressing many of the issues mentioned in this article to provide quality learning opportunities for all students. The key issues include selection and use of inquiry-centered science curricula, availability of effective professional development for teachers in science content and teaching strategies, creation of an organized system for supplying materials and equipment necessary to conduct science activities in classrooms, application of new approaches for assessing student learning, and building of support for new approaches within the school system and community (NSRC 1997).

Several initiatives within NSF's Directorate for Education and Human Resources support systemic science education reform. These include three cross-cutting large-scale programs: Statewide Systemic Initiatives, which coordinate and support efforts for science and mathematics education reform within individual states; Urban Systemic Initiatives, which perform similar roles within large urban centers; and Rural Systemic Initiatives, which target rural and economically disadvantaged areas (NSF 1997b). In addition, Local Systemic Change (LSC) projects support school systems and their community partners in reforming the delivery of science and mathematics education on a smaller scale, primarily through sustained teacher enhancement activities.

These four initiatives are complemented by efforts within NSF's Division of Undergraduate Education, which is promoting comprehensive changes in the education of future teachers by supporting cooperative, multi-year efforts to increase the quality and number of teachers who are well prepared in science and mathematics. Known as the Collaboratives for Excellence in Teacher Preparation, this program funds partnerships within and among academic institutions for the development of innovative approaches in the design of courses and curricula in science and mathematics (both content and teaching methods); the integration of mathematics, the sciences, and engineering; the use of advanced technologies; and the development of new methods of student assessment (NSF 1998).

Models for action

The NRC Standards describe important functions for scientists in K–12 science education: "Scientists must take the time to become informed about what is expected in science education in schools and then take active roles in support of polices to strengthen science education in their local communities." These roles can range from individual teacher–scientist collaborations that reach a single classroom to large-scale systemic science education reform projects that involve multiple academic research centers and several large school districts.

Individual teacher–scientist partnerships often develop informally when a scientist, frequently a parent, assists with a science demonstration, provides supplies, or judges a science fair. These natural introductory activities help scientists gain appreciation for the school environment and allow teachers and scientists to become acquainted and feel comfortable with one another. The "comfort" factor—being viewed as friendly, flexible, and eager to share—is essential for scientists who want to establish relationships with teachers and schools.

Many professional societies support scientists who work with individual teachers. The American Physiological Society (APS), for example, is building professional networks between and among classroom teachers and research scientists. The APS provides resources and teaching materials on the World Wide Web and in print publications, coordinates mentored research laboratory experiences for middle- and high-school teachers, and allows K–12 teachers and students to ask questions of life scientists via e-mail and fax (APS 1999). Similarly, the Society for Neuroscience (1999) has provided informational sessions and hands-on workshops at its annual meeting for the past several years to help scientists become acquainted with the challenges of K–12 science education and learn about ways to work with teachers. Generally, the most effective individual partnerships allow students (in addition to teachers) to interact with a scientist, to learn about science careers, to conduct meaningful investigations, and to see their teacher validated as a competent professional.

Individual partnerships, however, are destined to reach only a handful of students. Although the impact on these students can be significant, many more children are ultimately reached when scientists become involved in professional development activities for K–12 teachers and in the creation of instructional materials for use in classrooms. A number of noteworthy efforts have been highlighted by the Resources for Involving Scientists in Education (RISE) program, which is sponsored by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. RISE provides information and resources to help scientists and engineers play key roles in K–12 science education reform and, through its Web site, provides an excellent starting point for exploration (NAS 1999).

Numerous successful teacher enhancement projects provide evidence of the benefits of ongoing collaboration among multiple K–12 teachers and scientists. The Science and Health Education Partnership of the University of California–San Francisco (UCSF), for example, has actively partnered with the San Francisco Unified School District since 1987. With support from NSF and other sources, UCSF has teamed master teachers with scientists for professional development of other teachers, involved scientists in the development and implementation of inquiry-based science instructional programs, and implemented a professional development and student enrichment program to promote gender-equitable teaching strategies and girls' participation in science (Clark 1996). In Atlanta, Georgia, several local colleges and universities are collaborating on a program to place undergraduate science students in semester-long partnerships with local elementary school teachers. Through the Elementary Science Education Partners project, headquartered at Emory University, college students are recruited and trained to serve as "science partners," bringing their expertise and enthusiasm for science to inner-city classrooms. The program is supported by a district-wide LSC grant from NSF, and it coordinates its activities with the Atlanta Urban Systemic Initiative (NSF 1997a).

At Baylor College of Medicine in Houston, Texas, I and other members of the Center for Educational Outreach are providing intensive summer instruction, with year-round follow-up, to teams of elementary teachers through an NSF- and Eisenhower-supported program—the Summer, Science, Technology and Mathematics Lab—that is conducted in partnership with the Harris County Department of Education and three local school districts. This and other initiatives, supported by the National Institutes of Health and the National Aeronautics and Space Administration, has led to the establishment of a collaborative group of scientists, educators, master teachers, and other specialists who participate not only in teacher training but also in the development of integrated inquiry-based teaching materials in neuroscience (BrainLink), environmental health (My Health My World), and space life sciences (Moreno and Tharp 1999).

A few large collaborative projects, funded primarily by NSF, have focused on creating comprehensive elementary science curricula. Teaching series, such as Science and Technology for Children, which was developed by NSRC, and Full Option Science System, created at the Lawrence Hall of Science of the University of California, are examples of partnership projects that are reaching classrooms across the nation (NSRC 1997).

The examples listed here represent only a tiny fraction of ongoing partnerships nationwide that involve scientists from both academic and private organizations. Regardless of their size or specific objectives, all successful programs are characterized by an atmosphere of mutual respect and genuine appreciation of the roles played by each participant. Typically, scientists guide the presentation of science content in teaching materials and during professional development activities, contribute knowledge of science processes, serve as informal role models for teachers and students, mentor teachers or students in short- or long-term activities, assist with grant writing and submission, and, perhaps most important, communicate their enthusiasm for learning about the natural world. Teachers contribute their knowledge of classroom and school environments and cultures, their firsthand experiences with students of different ages, their expertise in producing activities and materials that are "friendly" to teachers and students, and their capacity to relate to parents, teacher colleagues, and other members of the education community.

Numerous professionals representing science, technology, engineering and mathematics participated in the development and review of the NRC Standards. The Standards' implementation, however, is a larger task, which will require even greater participation by scientists and others who understand the nature of science and its value to society. By promoting and being involved with implementation of the NRC Standards in schools, scientists can help maintain the connection between process and content in building science knowledge. The challenge for members of the science community will be to find ways to influence K–12 science teaching and learning while operating within the constraints imposed on them by their own commitments and institutions.

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