Chapter 6

Improving School Mathematics and Science Education

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Improving School Mathematics and Science Education

Now when 1 say "education, " I'm going *beyond what is* in NSF'S *Science and Engineering Education Directorate and looking at the education capabilities and programs of the foundation [NSF]. We have the responsibility to advance capabilities* along *the whole educational pipeline. 1 don't* think *any other agency, whether State or Federal, has that mission.*

Erich Bloch, 1988

The American system of public schooling is large, diverse, and stolid. Pressure to reform various features of the system, especially curricula, graduation standards, and the education of teachers, has been building since at least the early-1980s, and some change, much of it led by the States, has been realized. The "education reform movement, " as it is called, has drawn strength and encouragement from leaders in government, education, business, and higher educational Much of the pressure for reform has been bolstered by economic arguments, stressing the need for international competitiveness and the industrial advantages of a well-educated work force.

[1]See, for example, National Commission on Excellence in Education, ***A Nation at Risk*** (Washington, DC: U.S. Government Printing Office, 1983); and Gerald Holton (cd.), " 'A Nation at Risk' Revisited, " ***The Advancement of Science, and Its Burdens*** (Cambridge, England: Cambridge University Press, 1986).

THE SYSTEMIC NATURE OF THE PROBLEMS FACING AMERICAN SCHOOLS

The problems that face mathematics and science education in the schools are complicated and interrelated. In the broadest sense of the term, they are systemic. Reforms of any one aspect of mathematics and science teaching, such as course-taking, tracking, testing, and the use of laboratories and technology, can and have been undertaken. But each change is constrained by other aspects of the system, such as teacher training and remuneration, curriculum decisions, community concerns and opinions, and the requirements and influences of higher education.[2] Very little analysis has been undertaken of the costs and benefits of different kinds of improvements that could be made in mathematics and science education. A recent review suggested that schools':

> . . . influence on learning does not depend on any particular educational practice, on how they test or assign homework or evaluate teaching, but rather on their organization as a whole, on their goals, leadership, followership, and climate. . . . These organizational qualities that we consider to be the essential ingredients of an effective school —such things as academically focused objectives,

'Iris R. Weiss, OTA workshop summary, September 1987; F. James Rutherford, "Activities in Precollege Education, " ***Competition for Human Resources in Science and Engineering in the 1990s***, Symposium Proceedings (Washington, DC: Commission on Professionals in Science and Technology, Oct. 11-12, 1987), pp. 60-65; Arthur G. Powell et al., ***The Shopping Mall High School: Winners and Losers in the Educational Marketplace*** (Boston, MA: Houghton Mifflin, 1985); and Ernest L. Boyer, ***High School: A Report on Secondary Education in America*** (New York, NY: Harper & Row, 1983).

pedagogically strong principals, relatively autonomous teachers, and collegial staff relations—do not flourish without the willingness of superintendents, school boards, and other outside authorities to delegate meaningful control over school policy, personnel, and practice to the school itself. Efforts to improve the performance of schools without changing the way they are organized or the controls they respond to will therefore probably meet with no more than modest success; they are even more likely to be undone.3

Incremental and Radical Reforms

Against this background, a case can clearly be made for "starting all over" with a new system of organizing, administering, and even funding schools. The education system has evolved incrementally, and, during the last 200 years, has adapted to changing societal expectations, expanded its reach to almost the entire population of students up to age 18, been influenced by the changing economy of the United States, and responded to judicial intervention in many aspects of its organization, including its financing. These changes have been made on the superstructure of existing culture and practices, and have not necessarily resulted in the "best" system. But starting all over is not practical or politically feasible: too much is invested in the current system of mathematics and science education. The best short-term focus, therefore, will be on incremental improvements within the existing system.[4]

In 1985, Congress asked the National Science Foundation (NSF) to commission a special study of investment options for NSF to undertake in science and mathematics education. The contractor, SRI International, was asked to identify specific niches that the Science and Engineering Education Directorate of NSF could fulfill, given the existing structure, experience, and expertise of the Agency. The report of this study, published in June 1987, makes many concrete suggestions of ways NSF could use its special experience and expertise.' Ten current areas for future NSF investment are listed in box 6-A. The SRI report also discussed the trade-off between incremental change and wholesale renovation, arguing that while incremental improvements may not be the way to effect fundamental change, far-reaching innovations in science education not grounded in the current elementary and secondary school system will simply not be adopted.'

For now, incremental reform is the likely way American mathematics and science education will be improved. The remainder of this chapter examines some improvements that are taking place and others to be contemplated, against the background of intersecting local, State, and Federal interests.

Local and State Initiatives

Local and State initiatives could go a long way toward improving elementary and secondary mathematics and science education. Much can be and is being done to improve mathematics and science education at the local level of the school board and the school, from introducing magnet programs to re-equipping science facilities.

The many different initiatives spawned by schools and school districts are difficult to summarize because they do not form part of a single State, regional, or national plan. This does not detract from their importance; they can be highly beneficial. In 1983, the American Association of School Administrators (AASA) sent a questionnaire to 1,500 school administrators, mainly superintendents. From these and other data, AASA compiled a list of the top 10 most common actions already being taken by school districts to improve mathematics and science education. (See table 6-l.)

[3]John E. Chubb, "Why the Current Wave of School Reform Will Fail, " *Public Interest*, **No. 90,** winter 1988, pp. 28-49. Also see Peter T. Butterfield, "Competitiveness Plank Seven—Education: The Foundation for Competitiveness, " ***Making America More Competitive*** (Washington, DC: The Heritage Foundation, 1987), pp. 69-76.

[4]For the perspective of the former Secretary of Education, see William J. Bennett, ***American Education: Making It Work*** (Washington, DC: U.S. Department of Education, April 1988), esp. pp. *23, 31, 35, 41, 45.*

'Michael S. Knapp et al., ***Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation, Summary Report*** (Menlo Park, CA: SRI International, June 1987). Also see Robert Rothman, "NSF Urged to Assert Itself in Push to Improve Education, " ***Education Week,*** Sept. 9, 1987, p. 12.

Knapp et al., op. cit., footnote 5, pp. *36-39.* This chapter draws on the SRI report in discussing various National Science Foundation elementary and secondary mathematics and science education efforts.

Box 6-A. —Opportunities for Future Investment in K-12 Mathematics and Science Education: Recommendations by SRI International to NSF's Science and Engineering Education Directorate

Opportunities to Devising Appropriate Content and Approach

- **Redesign and improve existing mathematics curricula at all grade levels.** The amount of repetitive computation should be reduced, and the amount of effort devoted to other topics, such as the skills of mathematical problem solving, probability and statistics, and computer sciences, should be expanded.
- **Redesign the way in which elementary school science is taught.** Elementary school science, despite NSF's attempts in the 1960s to develop '"hands-on" curricula, is still very limited in scale and depth. NSF has begun an initiative in this area.' Similary, one priority should be to redesign and improve middle and high school curricula.
- **More effort shouId be made to match mathematics and science education with the needs and backgrounds of students, particularly females and minorities.** The reach of existing programs and curricula must be extended, but experiments are also needed to tailor teaching to the special needs of each type of learner.

Opportunities to Strengthen the Professional Community

- **The people who assist mathematics and science teachers, such as lead teachers, curriculum specialists, and science and mathematics coordinators, need more help and support.** Multiyear training programs, recognition programs, and development of stronger alliances between higher education and school districts would enhance this support function.
- **The number training to become mathematics and science teachers needs to be increased, and their training improved.** NSF could enhance the "professionalization" of the teaching force, the content of teacher training courses, and the utilization of knowledge about teacher recruitment and training programs.
- **Strengthen the informal science education community.** Educators out of schools—on television and in museums and science centers-are becoming increasingly important. These people need training and professional development, and would benefit from larger networks and closer collaboration,

Opportunities to Leverage Key Points in Educational Infrastructure

- **improve and expand publishing capabilities in mathematics and science education.** An emphasis on broadening the base of learners will require new and different teaching materials: current materials are largely aimed at the "science- and engineering-bound." Collaborative programs with existing publishers would help improve the textbook publishing process, and promotion of alternative publishing routes would help provide a diversity of materials that the current mechanisms of market operation are not able to support.
- **Improve testing and assessment methods and practices in mathematics and science.** The growing power of testing over curricular and teaching decisions indicates the urgency of developing and implementing tests that measure a broader range of skills, concepts, and attitudes than current fact-oriented tests. NSF's skill at research and development gives it special expertise in managing research programs in testing.
- **Work with State mathematics and science education reform leaders.** Interest among these leaders in improving the teaching of these subjects is strong, but their familiarity with the educational issues involved is limited. NSF could assist State-level groups to devise and implement reforms, and to develop networks.
- **Expand the proven power of informal education programs and assist their assimilation into schools.** These programs are effective at reaching and motivating large and diverse groups of students. Innovations are needed, as is better outreach to more communities.

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[1]The National Science Foundation's first solicitation in this area, in fiscal year 1986, addressed elementary mathematics curricula, and resulted in six awards. A second solicitation, also in fiscal year 1986, addressed elementary science curricula and aimed to develop ". . . partnerships among publishers, school systems and scientists/science educators for the purpose of providing a number of competitive, high quality, alternative science programs for use in typical American elementary schools." Among these latter awards has been the Technical Education Research Center's project in linking computers and science learning. A third round of awards was made in May 1988. See National Science Foundation, Directorate for Science and Engineering Education, "Summary of Grants, FY 19S4-86: Instructional Materials Development Program,'NSF 86-85, unpublished document, March 1987; National Science Foundation, Program Solication, "Programs for Elementary School Science Instruction II,'NSF 87-13, unpublished document, 1987; science, "NSF Announces Plans for Elementary Science," vol. 235, Feb. 6, 1987, p. 630; and "N. .S.F. Gives $7.2 Million for 'Hands-On' Science Material, " *Education Week*, May 2S, 1988, p. 19. On elementary science curricula generally, see Marcia Reecer, "Pointing Out and Disseminating," Science *and Children*, vol. 24, No. 4, January 1987, pp. 16-18, 1s8-160.

SOURCE: Office of Technology Assessment, 1988, based on Michael S. Knapp et al., *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation*, Summary Report (Menlo Park, CA: SRI International, June 1987), pp. 10-16.

Photo credit: William Mills, Montgomery County Public Schools

Education policy begins at the local level.

States are playing an increasing role in K-12 education, through finance, curriculum and graduation requirements, and assessment and monitoring. Most States are funding a growing proportion of the cost of public elementary and secondary education (see figure 2-1 in ch. 2), spurred by the warnings contained in the rash of educational reform reports of the early 1980s.[7] This activity has been chronicled in recent surveys by the Education Commission of the States and the Council of Chief State School Officers (CCSSO).[8]

These two reports document the ways in which States have become more active in four areas:

- curriculum requirements;
- assessment of the extent to which curriculum

[7]National Governors' Association, ***Results in Education–1987: The Governors' 1991 Report on Education*** (Washington, DC: 1987), pp. 36-37. "State," as used here includes the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Guam.

[8]Education Commission of the States, *Survey of State Initiatives to Improve Science and Mathematics Education* (Denver, CO: September 1987); Jane Armstrong et al., "Executive Summary: The Impacts of State Policies on Improving Science Curriculum," prepared for the Education Commission of the States, unpublished manuscript, June 1988; and Rolf Blank and Pamela Espenshade, *State Education Policies Related to Science and Mathematics* (Washington, DC: Council of Chief State School Officers, State Education Assessment Center Science and Mathematics Indicators Project, November 1987). For State actions in relation to all subjects, see ibid.; and Denis P. Doyle and Terry W. Hartle, "Leadership in Education: Governors, Legislators, and Teachers," *Phi Delta Kappan*, September 1985, pp. 21-27.

Table 6-1.—Summary of Kinds of Local Initiatives to Reform K.12 Mathematics and Science Education

The 10 most common and frequent actions being taken by school districts:

1. **Revise, reconstruct, and strengthen the science and mathematics curricula.** Committees are at work discarding old content, adding new units, and expanding the scope and sequence in established and new offerings. A major aim is to bring about an articulation of offerings, in kindergarten through grade 12.
2. Generate new activities to retrain, reeducate, and **lend a helping hand to classroom practitioners.** Inservice education, in doses more massive than ever before, goes on at an ever-increasing pace within school systems and on college campuses. Cooperation with colleges and universities is at a high level on behalf of both science and mathematics.
3. Modernize and expand facilities needed for science, providing better-equipped laboratories for upper grades, and offering teachers suitable working space for elementary hands-on science activities.
4. Make available new textbooks and other instructional materials for science and mathematics. They buy "packaged programs" (STAMM, COMP, SCIS, ESS), but, above all, districts develop their own curriculum guides, teacher resource handbooks, and units for students—all geared to local district philosophy, aims, and objectives.
5. **Raise requirements for the study of science and mathematics,** often under the spur of State legislation, at times by decision of boards of education. The big push is toward more years of science and mathematics at the secondary level, and more time spent on task in the elementary grades.
6. **Monitor science and mathematics programs more closely than ever before.** They assess, evaluate, and measure. Methodology, content, and student achievement are under close scrutiny at all times by principals, but more often by specialized personnel using new tools and instruments.
7. Go **into partnerships with industry, higher education, and community groups.** Out of these cooperative efforts—also called alliances and consortiums-come advanced content (from scientists and mathematicians); new opportunities for inservice education (from colleges and universities); and greater support for science and mathematics programs (from community and civic groups.)
8. **Devise new programs to attract and hold students** who have so far been largely bypassed by science and mathematics education—Blacks, Hispanics, American Indians, and other minorities.
9. **Support, with greater interest than ever before, extracurricular activities for science and mathematics students.** They seek the establishment of clubs and encourage greater student participation in science and mathematics fairs, olympiads, and other competitions—both for the able and the average student.
10. **Seize the role of advocacy,** sensing this is the time and opportunity to rebuild and strengthen the science and mathematics curriculums.

SOURCE: The material in this table is from Ben Brodinsky, Improving *Math and Science Education* (Arlington, VA: American Association of School Administrators, 1985), pp. 29-30.

requirements are met;

- providing special programs for female, minority, gifted and talented, handicapped, and learning disabled students; and
- recruitment of mathematics and science teachers and improvement of their skills.

Most of these initiatives are too recent to have been evaluated, and it is difficult to say which are effective and which not. CCSSO is developing a set of indicators for mathematics and science education to allow State-by-State comparison as well as national evaluation of trends.[9]

There is increasing corporate support of K-12 mathematics and science education, but its overall amount remains very small compared with public spending.[10] Industry can also contribute valuable resources in kind, such as equipment, trained scientists and engineers, and site visits. Much of this attention is driven by industrial concerns about the poor quality of high school graduates—the entry level work force to many firms–rather than the question of who will become scientists and engineers.

Course and Curriculum Requirements

States are trying to control and expand what students learn by means of curriculum requirements, tightened graduation requirements, and encouragements to teachers and students to address higher order thinking skills. With respect to graduation requirements, anecdotal data suggest that college admission requirements may be more important than State policies for the college-bound in science and engineering. Indeed, the trend toward tightening graduation requirements may actually be deleterious for this group, by stretching existing teaching resources in mathematics and science too thinly.

Many States have begun to issue reasonably detailed curriculum guidelines, and a few, such as California, have comprehensive guides built around an integrated approach to curriculum development, textbook adoption, and teacher training. Curriculum guides in mathematics and science are used by 47 States; most of these guides are not actually mandatory for school districts. Policies on the amount of time that should be devoted to mathematics and science in elementary schools have been adopted by 26 States. Of these States, most recommend, but do not require, that about 100 to 150 minutes per week be spent on K-3 science, and 225 to 300 minutes per week be spent on K-3 mathematics. For grades four to six, normal recommendations are 175 to 225 minutes per week on science and 250 to 300 minutes per week on mathematics. (See table 6-2.)*'

All but seven States (and all but four of the fully constituted States) set formal requirements for the award of a high school graduation diploma. (See table 6-3.) (The Constitution of Colorado explicitly forbids the State from setting such requiremerits.) Almost all of the States that do set formal requirements have, since 1980, steadily increased the number of mathematics and science courses that students must take. Of 47 States that set requirements, **36** require 2 courses in mathematics and 39 require 2 courses in sciences, Delaware, Florida, Guam, Kentucky, Louisiana, Maryland, New Jersey, New Mexico, Pennsylvania, and Texas each set a higher standard, requiring at least one more mathematics course for a total of three.

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[9]For the pitfalls of making and interpreting State-by-State comparisons of student performance, see Alan L. Ginsburg et al., "Lessons From the Wall Chart, " ***Educational Evaluation and Policy Analysis,*** vol. 10, No. 1, spring 1988, pp. 1-12.

[10]A recent estimate is that total spending in 1986 by 370 companies was about $40 million **(6** percent of total corporate spending on education), up from $26 million in 1984. See Council for Aid to Education, ***Corporate Support of Education 2986 (New*** York, NY: February 1988); Anne Lowrey Bailey, "Corporations Starting to Make Grants to Public Schools, Diverting Some Funds Once Earmarked for Colleges, " ***The Chronicle of Higher Education,*** Feb. 10, 1988, pp. A28-30; and Ted Kolderie, "Education That Works: The Right Role for Business, " ***Harvard Business Review,*** September/ October 1987, pp. 56-62.

[11]Blank and Espenshade, op. cit., footnote 8, table 1. There is no sound estimate of the average length of the elementary school day available. In 1984-85, it was estimated that the average public school day in elementary and secondary schools included about 300 minutes (5.1 hours) of classes. U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, ***Digest of Education Statistics 1987*** (Washington, DC: U.S. Government Printing Office, May 1987), table 89.

Table 6-2.—Comparison of Recommended and Actual Amounts of Time Devoted to Mathematics and Science in Elementary Schools

	Teacher estimates of average number of minutes per day spent on subject		
Grades/subiects	Actual in 1977	Actual in 1986	Recommended
Mathematics:			
K-3	*38*	*38*	*45-60*
4-6	*44*	*49*	*50-60*
Science:			
K-3	*19*	*19*	*20-30*
4-6	*35*	*38*	*35-45*

NOTE: There is no estimate of the average length of the elementary school day available. In 1984-85, it was estimated that the average public school day in elementary and secondary schools included about 300 minutes (5.1 hours) of classes. U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: U.S Government Printing Office, May 1987), table 89.

SOURCE Actual amounts of time from Iris R Weiss, Report *of the* 1985-88 *National Survey of Science and* Mathematics Education (Research Triangle Park, NC: Research Triangle Institute, November 1987), table 1, p 12 Recommended times from Rolf Blank and Pamela Espenshade, *State Education Policies Related to Science and Mathematics* (Washington, DC: Council of Chief State School Officers, State Education Assessment Center Science and Mathematics Indicators Project, November 1987), p 2

However, control of the *number* of mathematics or science courses alone is a relatively blunt policy tool, for it disregards the curricular con*tent* of those courses. In addition, mandating extra courses in mathematics and science will be of little use if there are too few well-qualified teachers available to teach them. Indeed, some argue that increasing graduation requirements may actually harm the college-bound in science and engineering, for teachers of the specialized courses that these students now take will be transferred to teach more mainstream courses. Schools with already poorly equipped science laboratory facilities will be asked to spread thin resources even thinner. Thus, tightening graduation requirements must be part of a balanced strategy that also provides adequate teaching and facilities for the new mandated classes in mathematics and science.

Even where States set mandatory minimum requirements, schools and school districts may set

Table 6.3.—Recommended Number of Courses in Mathematics and Science Needed for High School Graduation, by State (for class of 1987 unless specified)

	Courses for regular diploma		Courses for advanced/honors diploma	
	Math	Science	Math	Science
Alabama (1989)	2	2	3	3
Alaska	2	2		
Arizona.	2	2		
Arkansas (1988)	5 combined			
California.	2	2		
Colorado	Local board			
Connecticut	3	2		
Delaware ., ...	2	2		
District of Columbia . . .	2	2		
Florida	3	3	4	4
Georgia (1988).	2	2	3	3
Guam	3	3		
Hawaii	2	2		
Idaho (1988).	2	2		
Illinois (1988).	2			
Indiana (1989)	2	2	4	3
Iowa	Local board			
Kansas (1989)	2	2		
Kentucky	3	2	4	3
Louisiana (1988)	3	3		
Maine (1989)	2	2		
Maryland (1989)	3	2	3	3
Massachusetts	Local board			
Michigan	Local board			
Minnesota	O[a]	O[a]		
Mississippi (1989) .	2	2		
Missouri.	2	2	3	3
Montana.	2	1		
Nebraska	Local board			
Nevada.	2			
New Hampshire	2	2		
New Jersey (1990)	3	2		
New Mexico . . .	3	2		
New York.	2	2	2[a]	2[a]
North Carolina	2	2		
North Dakota	2	2		
Ohio	2	1		
Oklahoma	2	2		
Oregon	2	2		
Pennsylvania (1989) .	3	3		
Puerto Rico.	2	2		
Rhode Island (1989)	2	2	3	2
South Carolina .	3	2		
South Dakota (1989) .	2	2		
Tennessee.	2	2	3	3
Texas	3	2	3	3
Utah (1988)	2	2		
Vermont	5 combined			
Virginia (1988)	5 combined			
Virgin Islands	2	2		
Washington (1989)	2	2		
West Virginia	2	2		
Wisconsin	2	2		
Wyoming	Local board			

[a]New York State Regents courses for credit toward Regents diploma. Minnesota has no State requirements for grades 10-12, 1 math and 1 science required for grades 7-9.

KEY: Combined = 3 mathematics and 2 science or 2 mathematics and 3 science; Local board = requirements determined by local school boards.

SOURCE Rolf Blank and Pamela Espenshade, *State Education Policies Related to Science and Mathematics* (Washington, DC: Council of Chief State School Officers, State Education Assessment Center Science and Mathematics Indicators Project, November 1%37), table 2.

[12]Ben Brodinsky, ***improving Math and Science Education*** (Arlington, VA: American Association of School Administrators, 1985), pp. 7-8. Some argue that the trend toward increased control over classroom teaching and learning is both a distinguishing trait of American education and a major weakness. See Arthur E. Wise, "Legislated Learning Revisited, " ***Phi Delta Kappan***, January 1988, pp. 328-333.

higher standards. Most of those States that do not have minimum requirements set recommended graduation requirements and apply strong pressure on districts to abide by them; some States, such as Michigan, even offer financial incentives to those that do.

Several States, including Indiana, Kentucky, Idaho, Virginia, Texas, and Missouri, now offer advanced or honors diplomas designed explicitly for the college-bound, that require additional coursework or demonstration of competence *(again see table* **6-3).** New York has long offered a "Regents" examination, designed for the college-bound. Data suggest that this examination is effective in encouraging students to take more preparatory mathematics and science courses than is common in other States. 13

Assessment of What Students Learn

States are making efforts to ensure that teachers address higher order thinking skills in science and mathematics teaching, either through teacher training programs, curriculum frameworks, or through competency testing programs. The Missouri Mastery and Achievement Test, for example, has been designed to include items that assess higher order thinking skills. Higher order thinking, although much sought after, is difficult to define and there appears to be little agreement on how it can be taught.

Statewide testing programs are used in 46 States, indicating a broad response to the public pressure for accountability. But only 30 of these States include science knowledge in these tests, whereas 43 include mathematics. Five States (Alaska, Montana, Nebraska, Ohio, and Vermont) delegate responsibility for assessment to school districts or schools themselves. A recent OTA survey found that 21 States now require students to pass a minimum competency test in designated basic skill areas prior to graduation. Fifteen States include mathematics in such tests and five include science. CCSSO found that **30** States either have, or are planning, competency tests in mathematics, and 6 States in science. 14

[13] Penny A. Sebring, "Consequences of Differential Amounts of High School Coursework: Will the New Graduation Requirements Help?' *Educational Evaluation and Policy Analysis,* vol. 9, No. 3, fall 1987, pp. 258-273.

"U.S. Congress, Office of Technology Assessment, State Educational Testing Practices, " Background Paper, NTIS #PB88-155056, December 1987

FEDERAL INVOLVEMENT

State and local programs have long been supplemented by Federal efforts.[15] Although these programs have been controversial politically, because of the constitutional limitations on Federal involvement in education, many in mathematics and science education have been reasonably successful in meeting their stated objectives. They are reviewed below.

Given the generally accepted importance of education to the national economy, the Federal Government has long had not only an interest in education issues, but also a mandate to redress inequities in access and provide opportunities for various disadvantaged groups. From the time of the Northwest Ordinance of 1787, the Government has indirectly supported education through financial and land contributions. In 1862, when the U.S. Office of Education was established, that role was augmented by the task of information gathering, research, and analysis. At the turn of the century and for the next 20 years, in response to the increasing industrialization of the Nation, the Federal Government began to take an interest in manpower needs and training and, under Federal law, sought to promote vocational training.

The Federal Interest in K-12 Mathematics and Science Education

Large-scale Federal funding of basic research began after World War II, when demand for research scientists and engineers was strong. NSF,

[15] See Deborah A. Verstegen, 'Two Hundred Years of Federalism: A Perspective on National Fiscal Policy in Education, " *Journal of Education Finance,* vol. 12, spring 1987, pp. 516-548.

created in 1951, was given a mandate to ensure the adequacy of science and engineering education and manpower at all levels. NSF's prime education goal, however, was the cultivation and education of enough scientific talent to fuel the new research-intensive industries and national laboratories. Ever since, NSF has made a significant contribution, by leadership and funding, to science education, but skewed toward students destined for science and engineering careers.

Serious concerns about the adequacy of mathematics and science education developed in the mid-1950s, as Cold War competition with the U.S.S.R. and the baby boom population strained educational resources. Significant NSF involvement in science education, however, originated with the "Sputnik crisis" of the late-1950s. The National Defense Education Act of 1958 was a bold new law to bolster supplies of scientific and other skilled manpower. The act gave grants to school districts to improve or build laboratory facilities and sponsor teacher training in mathematics and science, as well as foreign language instruction. Congress increased funding for science education at NSF, to the point where education was apportioned at about one-half of NSF's buclget.[16] The 10 years following Sputnik were the "golden years" of NSF's mathematics and science education effort, highlighted by funding for teacher training institutes, curriculum development, informal education, and research participation programs for high school students and their teachers.

Federal funding for education in all subjects reached its zenith in the early -1960s, when anxiety about regional, economic, and racial disparities in educational provision led Congress to adopt ambitious programs of support for underprivileged students. The Federal role in promoting equity became generally accepted as a consequence of the implementation of these programs, which were successful in achieving their limited goals .17

"Myron J. Atkin, "Education at the National Science Foundation: Some Historical Perspectives, An Assessment, and A Proposed Initiative for **1989 and** Beyond," testimony before the House Subcommittee on Science, Research, and Technology of the Committee on Science, Space, and Technology, Mar. 22, 1988.

[17]Michael S. Knapp et al., ***Cumulative Effects of Federal Education Policies on Schools and Districts: Summary Report of a Congressionally Mandated Study*** (Menlo Park, CA: SRI International, January 1983).

The Reagan Administration's policy of diminishing, if not removing, Federal involvement in education was enacted by major cuts in education programs at the beginning of the **1980s.** Federal support fell from about 8 percent to **4** percent of total national education expenditures. The "new federalism" ideology held that funds were to be apportioned among States on an entitlement basis; States should be allowed to spend funds as they saw fit, and not necessarily in accord with any Federal policies or programs.[18] In 1981-82, the Science and Engineering Education Directorate (SEE) of NSF was disbanded. However, this latter move was most unpopular with mathematics and science educators and in 1983, under pressure, the SEE Directorate was resuscitated.[19]

By 1984, continuing anxiety about international economic competitiveness and the apparently poor quality of public schooling led Congress to pass the Education for Economic Security Act (EESA), designed to promote teaching of mathematics, science, and foreign languages. Title 11 of this act directs the Department of Education to provide grants to school districts and States to improve the teaching of mathematics, science, computer science, and foreign languages that are critical to national economic well-being. Although the Administration has proposed extending the criteria for funding under this program to all subject areas, this proposal has not been supported in Congress. Title II was part of the package of education programs reauthorized in **1988;** the new name for Title 11 is the Dwight D. Eisenhower Mathematics and Science Education Act.[20]

The Federal Division of Labor in Science Education

Today, Federal mathematics and science education programs are enjoying a resurgence of

[18]See Paul Peterson, ***When Federalism Works*** (Washington, DC: The Brookings Institution, 1987).

[19]The power of the science education lobby is described in Morris H. Shames, "A False Alarm in Science Education, " ***Issues in Science & Technology, vol. 4,*** spring 1988, pp. 65-69.

*°For a synopsis of elementary and secondary education legislation introduced in fiscal year 1988, including that targeted to science and engineering education, see U.S. Congress, Congressional Research Service, ***Major Legislation of the Congress*** (Washington, DC: U.S. Government Printing Office, August ***1988),*** Issue No. 3, pp. MLC-016 - MLC-021.

funding and considerable bipartisan support, even in the current stringent budgetary climate. They come from three sources:

- NSF, which is generally recognized as the lead agency for mathematics, science, and engineering education;
- the Department of Education, which has overall charge of Federal education programs, but within which mathematics and science education is a relatively low priority; and
- mission agencies that have a direct interest in developing a pool of skilled scientific talent; such agencies include the Department of Energy (DOE), the Department of Agriculture (USDA), the National Institutes of Health (NIH), and the National Aeronautics and Space Administration (NASA).

There is an important difference between NSF and the Department of Education in the scale of the programs that each mounts, Whereas NSF's entire budget is now somewhat under $2 billion annually (and is principally spent on research), that for the Department of Education is about **$20** billion. Although most of the Department's programs provide funding either on a categorical basis to providers of education or to ensure equitable access to education, the Department has one program specifically addressed to K-12 mathematics and science education: Title II of the EESA. Appropriations for Title 11 have been comparable to NSF spending on precollege education, but represent only a few percent of the entire spending of the Department of Education. The dollars, however, are distributed to the States in a formulaic way, with little technical assistance to implement their use or monitor their impacts. No special interest in programmatic mathematics and science education at the Department of Education is apparent.

Some argue that mathematics and science education programs conducted by NSF might flourish were they relocated in the Department of Education. Proponents say that the Department of Education would not concentrate only on the brightest and best students and on funding proposals from rich research universities the way NSF does.[21] In addition, some note that NSF is most comfortable in dealing with and through universities and, until recently, has made few efforts to work closely with States and school districts, as favored by the Department of Education. NSF is now attempting to improve its working relationships with the States. Giving a greater role to the Department of Education in mathematics and science education programs is rejected by most of NSF's existing clients in the scientific and science education research communities, among whom the Department of Education has little credibility.[22]

Consideration of the propriety of Federal education programs is, at root, a highly ideological battle and invokes constitutional concerns. From a public policy perspective, it is important to examine whether and how Federal funding of mathematics and science programs changes the actions that State and local bodies would otherwise have taken. Do Federal programs merely replace funds that would otherwise have been raised by State and local sources or do they allow States and local school districts to do things that they would not or could not otherwise do? Conversely, do Federal programs merely encourage States and local school districts to avoid reforming their own operations, including possibly raising local and State taxes?

There are no clear answers, but Federal programs may work best when they identify aspects of the K-12 education system that have fallen through the cracks of the different agencies involved in education, and address those aspects directly. For example, the "Great Society" legislation of the 1960s improved educational provision to poor and disadvantaged children, and the National Defense Education Act was successful in supplying science equipment and teacher training to school districts.

[21]This is addressed by Don Fuqua in his personal conclusions following hearings by the Science Policy Task Force, *American Science and Science Policy Issues,* Chairman's Report to the Committee on Science and Technology, U.S. House of Representatives, 99th Congress, 2nd Session, December **1986**, pp. 80-84 (Committee Print),

[22]See Atkin, op. cit., footnote 16,

NSF's Role in Science and Engineering Education

NSF has been the lead Federal agency in precollege science and mathematics education since the agency's inception. NSF in recent years has been ambivalent towards science education.[23] With its limited funding of K-12 programs, NSF aims to be a catalyst for interplay between the research community and schools and school districts—to generate new ideas for others to implement; to leverage its funding through States, school districts, and foundations; and to do research on mathematics and science education. In its 1987 study, SRI International suggested that NSF's approach to K-I2 mathematics and science education should be based on three principles:

- identifying targets of opportunity that are important problems and amenable to NSF's influence;
- supporting core functions of professional exchange among scientists, engineers, teachers, and education researchers; data collection; and experiments in education; and
- investing as part of a coherent strategy to broaden the base of science learners.

The SRI report identified six characteristics of the SEE Directorate that distinguish it from other actors:

- national purview of problems and solutions;
- quasi-independent status rather than an executive branch department;
- connection to the mathematics, science, and engineering communities;
- large amounts of discretionary funding (i.e., those that are allocated on a project/proposal basis);
- a central position vis-a-vis various actors involved in improving mathematics and science education; and
- an established track record in K-12 mathematics and science education programs, especially at the secondary level .24

NSF also attempts to define a leadership role in mathematics and science education issues, a function which, especially in the decentralized American education system, should not be underestimated." The ongoing challenge for NSF in science and engineering education will be locating particular niches where it can make a useful and detectable difference, rather than being an agent of change on a broad scale. Investments by the SEE Directorate in science and mathematics education must differ from support for science and engineering research. Developing NSF's capability to invest strategically in education programs may take 5 to 10 years. 'b

Evaluation of Federal Science and Mathematics Education Programs

Too little is known about the effectiveness of previous and current Federal efforts to improve elementary and secondary mathematics and science education. Evaluation of these efforts, for a number of reasons, is very difficult. (See box 6-B.) This review has been supported by an informal questionnaire survey of members of the National Association for Research in Science Teaching (NARST), an association of university researchers in mathematics and science education that aims to improve teaching practices through research. Many Federal programs in this area have been tried, and appendix C lists some of them. Most have emphasized science rather than mathematics.

Three principal Federal programs have been designed to improve mathematics and science education:

- NSF-funded teacher training institutes;
- NSF-funded curriculum development; and
- Title II of the EESA, administered by the Department of Education.

[23]See Deborah Shapley and Rustum Roy, Lost *at the Frontier: U.S. Science and Technology Policy Adrift* (Philadelphia, PA: 1S1 Press, 1985), pp. 109-114; J. Merton England, *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945-1957* (Washington, DC: U.S. Government Printing Office, National Science Foundation, 1982), ch. 12; and U. S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School, OTA-SET-377* (Washington, DC: U.S. Government Printing Office, June 1988), pp. 104-107.

[24]Knapp et al., op. cit., footnote 5, pp. 9-1o.

[25]Atkin, op. cit., footnote 16, p. 10.

[26]Knapp et al., op. cit., footnote 5, p. 5.

Box 6-B.-Problems in Evaluating Science Education Programs

Much of the current literature and data on the effectiveness of previous Federal efforts in science education is of poor quality and has limited utility for policy purposes. To be useful for policy, research must measure, quantitively or qualitatively, the effects of a particular program upon a prior situation. It must, therefore, measure what was there before, what happened after, and describe mechanisms by which the addition of a program led to changes apparent by the time of the final obseervation. Ideally, research should also address the relation between the costs of the program (in money, time, and effort) and its results.

Shortcomings of current research have two origins: 1) the fundamental scientific difficulty of defining and conducting good educational evaluation studies, and 2) idiosyncratic problems with samples and interpretations of research.

The fundamental difficulty is that there is no consensus on what attributes of students should be considered definitive "output" or "input" measures to an educational intervention. For example, many studies measure the student's achivementt on multiple-choice tests. Other valid output measures might equally be related to discipline and behavior in school, attitudes and interest in the subject, manual skills, the ability to achieve higher order thinking and reasoning about problems, and the extent to which students feel that they have mastered science and feel confident about it. At the moment, there is broad agreement that standardized achievement test scores should not be used as definitive measures of the outputs of education, but there is no consensus on what combination of other output measures should be used instead.

Such difficulties aside, practical research in the literature often fails to explain fully the effects of programs. Studies of programs that identify highly atble children and educate them apart from their peers often show that these children's achievement scores increase more rapidly than those of their age peers. To determine the contribution to achievement scores added by the program, account must be taken of the differential in the rise of scores (due, for example, to maturation) that would have occurred in any case; observations on a control group should be part of the analysis.

In addition, problems in reaching conclusions that are of national relevance arise from the difficulty evaluators have in gaining access to already-beleaguered schools to study programs, and from the expense of doing national evaluations of the worth of particular programs. Schools are increasingly reluctant to allow researchers access to classrooms, since they feel that they are asked to provide too much information already, with too much of it being used against them. These factors sometimes lead researchers to use small samples chosen from unrepresentative school environments for their studies, which diminish the force of research findings. Sometimes researchers argue that the results can be extrapolated to much larger populations, but that argument can only be sustained when other characteristics of the populations, such as socioeconomic status, ethnic composition, and urbanicity of the school chosen, are matched.

NSF Teacher Training Institutes Program

Between 1954 and 1974, NSF spent a total of over $500 million (or over $2 billion in 1987 dollars) on teacher training institutes, most of them for secondary school teachers." These institutes came in several forms. Most were full-time summer programs, others part-time after-school programs, and others full-time academic year programs. Some were aimed at high school teachers, others at elementary and middle school teachers, and others at science supervisors. At that time, the consensus was that the teaching force was deficient in content knowledge about science, and most of the institutes focused on improving teachers' knowledge about science, largely by means of lectures. Few of them addressed teaching practices. Most institutes were based at colleges and universities, which organized the programs and paid teachers stipends and travel expenses for attending.

By today's standards, the model that these institutes adopted—that giving mathematics and science teachers better subject knowledge would lead to better teaching—seems rather primitive. Any replication of these institutes would now focus on achieving a balance between knowledge and experience of how to teach science and mathematics together with what to teach. Nevertheless, evi-

[27]1 bid., vol. 1, p. 133. Expression in 1987 dollars is an OTA estimate.

dence suggests that the former mathematics and science teaching force was so poorly endowed with subject knowledge that emphasis on content over practice was largely inevitable.

At their peak in the early -1960s, about 1,000 institutes were offered annually, each with between 10 to 150 teachers meeting over a 4- to 12-week period; just over 40,000 teachers were reached annually (about 15 percent of the high school mathematics and science teaching force). The institutes were reorganized in **197'0, by which time** NSF had judged that the institutes had reached about as many teachers as any voluntary program ever would. A survey taken in 1977 found that many teachers had participated in NSF-funded institutes. The survey indicated that nearly **80** percent of mathematics and science supervisors had attended an institute, as had 47 percent of science teachers and 37 percent of mathematics teachers of grades 10 to 12. Only about 5 percent of teachers of kindergarten through third grade had attended such an institute.

Improvement of the skills of the elementary teaching force will always be difficult, because there are ***over*** 1 million individuals who teach at least some elementary mathematics and science (along with many other subjects), and because university-based mathematics and science educators generally find it harder to reach elementary teachers than they do high school teachers. For example, it is estimated that NSF's current efforts reach, at most, 2 or 3 percent of secondary mathematics and science teachers .28

Evaluation of the effects of these institutes has yielded no consensus on their usefulness. Teachers who participated are enthusiastic about them and remember them as stimulating and professionally refreshing. The General Accounting Office reviewed research on NSF-funded institutes and found little or no evidence that such institutes had improved student achievement scores.[29] Whereas NSF remains cautious in claiming effectiveness, many science educators think that the institutes were very successful. Various studies, including one by the Congressional Research Service in 1975, found that the institutes had positive effects.[30]

NSF did not attempt a systematic comprehensive evaluation of its own during the lifetime of the institutes. The institutes concentrated on improving the mathematical and scientific knowledge of teachers, but there is no direct relationship between teachers' knowledge, their effectiveness as teachers, and educational outcome measures such as students' achievement test scores .31 In practice, teachers need both some knowledge of mathematics and science and some pedagogical skills to be effective teachers.

Anecdotal evidence drawn from a history of this program and from the OTA survey of NARST members indicated that the teacher institutes program had these important effects:

- It brought teachers up-to-date with current developments in science.
- It brought teachers closer to the actual process of doing science and thereby improved both their identification with, and sense of competence in, science.
- It helped teachers share common solutions and problems, and gave them a network of peers that they kept in touch with many years after the programs ended.
- It allowed teachers to do experimental work in science, which many of them had never done before, and thereby encouraged them to replicate this experience for their students.
- It helped define leaders for the science education community, who now are effective voices for this community in professional meetings and policy debates.

[28] Ibid., vol. 1, pp. ***133-134.***

[29] Such a *post hoc* measure, however, may bear no relation to the ***a priori*** goal of the institutes, namely, to update teacher's knowledge. See U.S. Congress, General Accounting Office, *New Directions for* ***Federal Programs To Aid Mathematics and Science Teaching,*** GAO/PEMD-84-5 (Washington, DC: U.S. Government printing Office, Mar. 6, 1984).

[30] U S. Congress, Congressional Research Service, ***The National Science Foundation and Pre-College Science Education:*** *19.50-1975,* Committee Print of the U.S. House of Representatives Committee on Science and Technology, Subcommittee on Science, Research, and Technology, January ***1976;*** Hillier Krieghbaum and Hugh Rawsom, ***An Investment in Knowledge (New*** York, NY: New York University Press, 1969); and Victor L. Willson and Antoine M. Garibaldi, "The Association Between Teacher Participation in NSF Institutes and Student Achievement, " ***Journal of Research in Science Teaching, vol.*** 13, No. 5, 1976, pp. 431-439.

[31] Knapp et al., op. cit., footnote 5, vol. 1, p. 130.

- It recognized the importance of the work of mathematics and science teachers.
- It inspired and invigorated teachers to face another year of teaching.

Among problems with the institutes, however, were the following:

- Since teacher participation was voluntary, only those teachers who were the most interested and motivated in science teaching participated. The least interested and least qualified shunned the program, which consequently reached at best only about one-half of all teachers (though this is not an insignificant number).
- Since many of the institutes offered graduate credit, the program helped subsidize students' progress toward master's and doctoral degrees in education. Possession of these degrees may have helped impel good teachers out of active teaching into administration, or into other jobs entirely.
- The institutes succeeded in conveying much information about new developments in science, but gave teachers few clues as to how to teach this information to their classes.
- The institutes were typically lecture courses.

The costs of the teacher institutes were large, particularly for the academic year institutes, for which teachers were pulled from classrooms. Typical costs today for teacher institute programs are reported at about $25 to $40 per hour per teacher. If a minimum of 100 hours is assumed for length of the institute to make it meaningful, for a total cost per teacher of about $3,000, it would cost about $600 million to put all secondary mathematics and science teachers through one institute each.[32]

A small program of teacher institutes is now funded through the Teacher Preparation and Enhancement Program at NSF. In general, these put more emphasis on teaching techniques in mathematics and science than did the earlier institutes. Evaluations of these institutes indicate that they are having some success.[33]

Any future replications could build on successful NSF-sponsored models for inservice education, and would need to be based on a stronger partnership between school districts and universities than existed 20 years ago. Alternatively, NSF could try to act as a catalyst, persuading States and school districts to fund such inservice education directly.[34] Either way, the school must be recognized as the appropriate unit; teachers alone are neither the problem nor the solution. Organizational change is needed, and that impinges on all aspects of the system, from the classroom and school administration to the local district and State jurisdictions.

NSF-Funded Curriculum Improvements

In the 1960s and 1970s, NSF spent about $200 million on over 50 curriculum reform efforts. Their main focus was on the sciences rather than mathematics, and the new curricula have had a significant impact on the science education of many students.

To protect against Federal domination of curriculum, NSF did not review these projects once completed and ensured that the materials were held and disseminated by the developer rather than by NSF. Nevertheless, a fifth grade social studies curriculum, "Man: A Course of Study," attracted considerable criticism and congressional scrutiny in 1975; some critics found it offensive and unacceptable for children. NSF has since been extremely cautious in curriculum development ever since.

The curricula were almost all developed by teams headed by scientists, but often involved mathematics and science educators, and general educators; they were largely designed to convey the content and structure of the separate scien-

[32] Ibid., vol. 1, p. 132.

[33] Renate C. Lippert et al., "An Evaluation of Classroom Teaching Practices One Year After a Workshop for High School Physics Teachers," unpublished paper, May **1987;** and Margaret L. While et al., "Biosocial Goals and Human Genetics: An Impact Study of NSF Workshops," Science Education, vol. 71, No. 2, 1987, pp. 137-144.

[34] Or the National Science Foundation could concentrate on developing a smaller number of lead mathematics and science teachers who would then enthuse the remaining teacher force. This latter strategy is advocated in the recent SRI report, primarily because of the cost and difficulty of organizing another mass program to reach all mathematics and science teachers. Such a program, however, would focus change one further step away from students' actual learning about mathematics and science than even the teacher institute program would. See Knapp et al., op. cit., footnote **5,** p. 135.

tific disciplines.[35] Many believed that the high school curricula were too demanding, however, and worked well only for those planning college majors in science and engineering. Many believed that the scientists dominated the projects and that feedback on the new materials was not sought.

In 1968-69, it was estimated that nearly 4 million students (about **10** percent of the total) were using some kind of NSF-funded curriculum materials. A 1977 survey found that about one-half of the science classes in grades 6 to 12 were using such materials, although only about 10 percent of mathematics classes in these grades were.[36] NSF recently reinstated curriculum development, and is funding a series of three-way collaborative projects (involving publishers, universities, and school districts) to develop elementary science curricula,

Research reflects a consensus that the new curricula worked quite well. A review of evaluation studies found that, compared to control groups, students taking new curricula scored higher on achievement tests, had more positive attitudes toward science, and exhibited fewer sex differences in these attributes. Students taught by teachers who had been through preparatory teacher institutes for the curricula scored more highly than their peers taking the new curricula without this benefit.[37] It is clear that successful implementation of new curricula is very closely tied to teacher training; curriculum projects are of little use without support for teachers to master the new curriculum and put it into practice. Earlier elementary science education curricula, such as the Science Curriculum Improvement Study (SCIS), Elementary Science Study (ESS), and Science: A Process Approach (SAPA) did not become well established in schools largely because teachers were ill-prepared to teach them.[38]

Among the positive effects of new curricula were a spill-over effect to the entire mathematics and science curriculum, such that traditional textbooks from commercial publishers began to adopt many of the techniques, such as hands-on science. The main NSF-funded mathematics curriculum, the School Mathematics Study Group, explicitly aimed at affecting publishers' own curricula .3"

The success of new curricula is partially attributed to the considerable research that went into them. Many are still in use in some schools; they have influenced teachers and textbooks ever since. Many teachers have extensive experience with these curricula, and now know how to avoid some of the problems that the curricula can cause.

NARST members particularly cited the Biological Sciences Curriculum Study (BSCS), the ESS, the SAPA, and the SCIS (the last three being elementary science curricula), as effective and valuable curricula. Many of these curricula have apparently been translated and adopted for use in schools in South Korea and Japan. It has been estimated that the BSCS has been used in about one-half of all biology classes in the United States. One-quarter of those who graduated with a baccalaureate degree in physics in 1983-84 had taken BSCS physics in high school.'"

Problems cited with these curricula included:

- A lack of adequate financial and moral support to teachers introducing the new curricula.
- A focus on "pure" science rather than its real-life applicability.
- A design with only the future scientist and engineer in mind, which frustrated large numbers of mainstream students.
- A domination by research scientists rather than science educators, precluding develop-

[35]Ibid., vol. 1, p. 92.

[36]Iris R. Weiss, ***Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education*** (Research Triangle Park, NC: Center for Educational Research and Evaluation, 1978), p. 83.

[37]A comprehensive analysis of 81 other studies is reported in James A. Shymansky et al., "A Reassessment of the Effects of 60's Science Curricula on Student Performance: Final Report, " mimeo, n.d. (a reworking of material originally published in 1983). Also see Patricia E. Blosser, "What Research Says: Research Related to Instructional Materials for Science, " *School* Science *and* Mathe-***matics, vol.*** 86, No. 6, October 1986, pp. 513-517; and Ted Bredderman, "Effects of Activity-Based Elementary Science on Student Outcomes: A Quantitative Analysis, " ***Review of Educational Research,*** vol. ***53, No. 4,*** winter 1983, pp. 499-518.

'Knapp et al., op. cit., footnote 5, vol. 1, p. 68. Ironically, anecdotal evidence suggests that these programs were especially successful with minority and disadvantaged students (Shirley Malcom, American Association for the Advancement of Science, personal communication, August 1988).

[39]Knapp et al., op. cit., footnote ***5,*** p. 48.

[40]Ibid., vol. 1, p. 92.

ment of a needed team approach to the design and implementation of the curricula.
- An approach embracing a view of science as a collection of neutral and immutable facts, to the exclusion of other conceptions of science.

Today's science curricula have slipped back into stressing facts at the expense of reasoning and understanding. One approach to future science curricula might be to disregard traditional disciplinary boundaries in science, and focus on hybrid disciplines or unifying themes and ways of observing and measuring. Many science-intensive schools integrate science with mathematics courses, an innovation that could be followed by most schools. In any case, the design of new curricula requires the active participation of the relevant scientific research communities .41

Mathematics curricula also need to be improved. Less emphasis needs to be placed on traditional rote learning. The curricula could concentrate on new developments in mathematics and its applications, such as mathematical problem solving, probability and statistics, and computer science. Deficiencies of mathematics curricula have been demonstrated by data collected for the international comparisons of achievement .42 Curricula need to reflect the availability of the hand-held calculator. One example of a reform in progress is the new Mathematics Framework for California Public Schools, which encourages calculator use from primary grades upward.

Title II of the Education for Economic Security Act of 1984

Title II of the EESA (Public Law 98-377 as amended by Public Law 99-159 and Public Law 100-297) was a major congressional initiative to address the problems apparent in mathematics and science education in the early -1980s. It provides funds to both States and school districts to improve the skills of teachers and the quality of instruction in mathematics, science, computer learning, and foreign languages in both public and private schools. Title II established teacher training as first priority and directed that the funds allocated to school districts must be spent on training. Only if school districts demonstrate to States that there is no further need for such training can such funds be used for other purposes, such as equipment and materials purchases or training in foreign language or computer instruction. '3 The legislation also contains provisions intended to boost the participation of "underrepresented" and "underserved" groups. The legislation was reauthorized in 1988 (Public Law 100-297), and renamed the Dwight D. Eisenhower Mathematics and Science Education Act.

Title II has been funded unevenly by Congress: $100 million was appropriated in fiscal year 1985, $42 million in fiscal year 1986, $80 million in fiscal 1987, and $120 million in fiscal year 1988. For comparison, the total expenditure on public and private elementary and secondary education in 1986 was about $140 billion; the total spending on mathematics and science teacher training was probably about $500 million to $1 billion. Total spending by the Department of Education was $19.5 billion in fiscal year 1987 (so that Title II was a small portion of the Department's total effort). Another way of evaluating spending on Title II is to recall that, nationally, a $40 million education program equates to a spending of $1 per pupil *or* $20 per teacher.

The Department of Education's implementation of Title II has been slow. Although funds for fiscal 1985 were provided by Congress, grant awards were not announced until July 2, 1985, immediately after the end of the school year (effectively delaying implementation by 12 months). However, the Department now hosts regular meetings of State Title II coordinators and publishes some information on exemplary State and local pro-

[41]See Philip W. Jackson, "The Reform of Science Education: A Cautionary Tale," *Daedalus*, vol. 112, No. 2, spring 1983, pp. 143-166.

[42]Curtis C. McKnight et al., *The Underachieving Curriculum* (Champaign, IL: Stipes Publishing Co., January 1987); and Knapp et a]., op. cit., footnote 5, vol. 2, pp. 35-60.

[43]Even then, no more than 30 percent of the funds provided to each school district can be used to purchase computers or software, and no more than 15 percent can be used for foreign language instruction. Note also that some of the funds appropriated under the act are spent on these areas via the Secretary's Discretionary Fund (see below).

grams that have been funded through the Title II program."

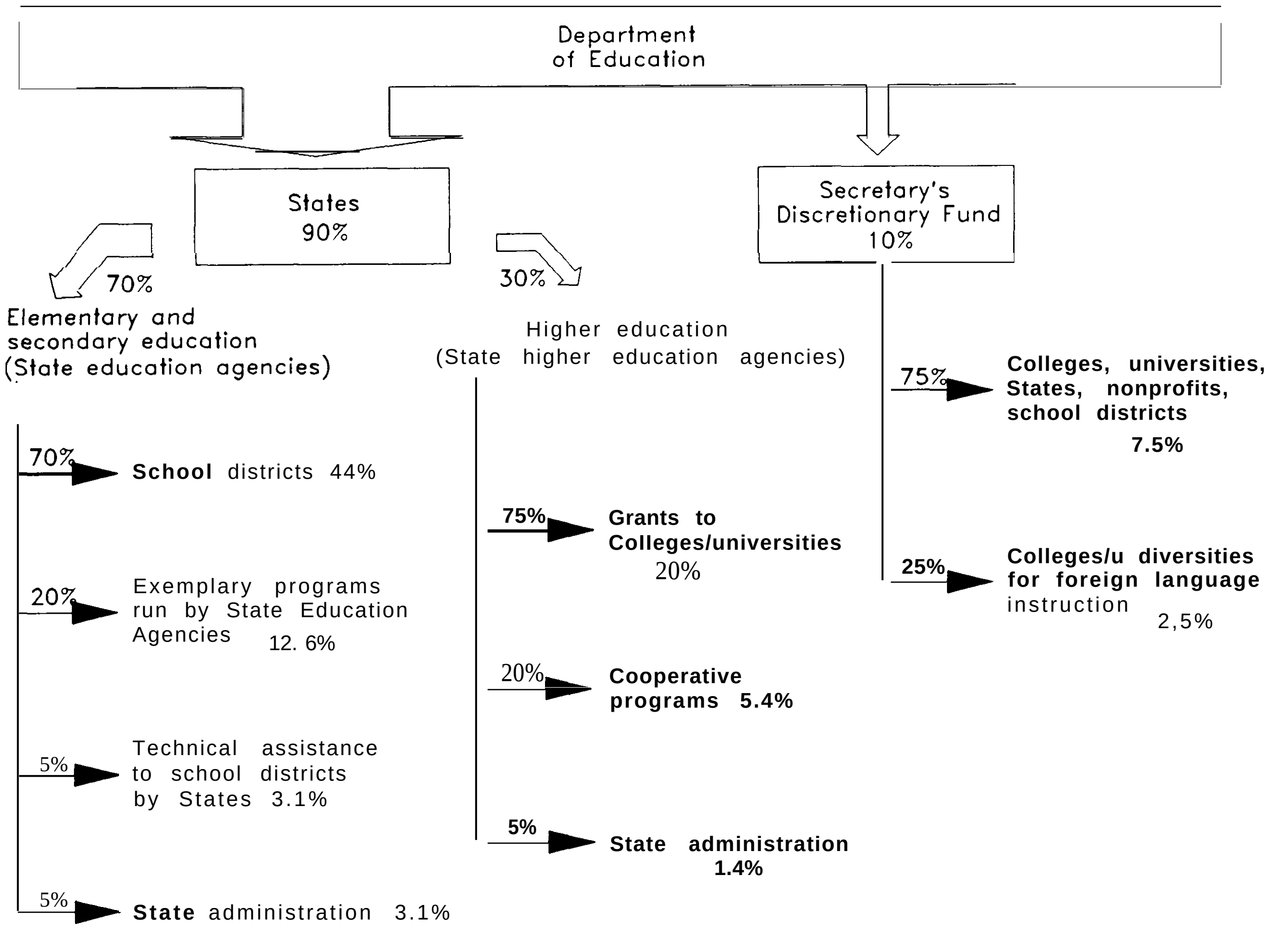
The legislation specifies in some detail the intended fate of the sums appropriated, leaving relatively little discretion to the Department of Education, the States, or school districts. It is worth examining the provision of the legislation in some detail to understand the way in which mathematics and science education programs administered through the Department of Education operate. (See figure 6-1.)[45]

Of the funds appropriated under Title II, 90 percent is sent straight to the States as categorical grants. Nine percent is retained by the Department of Education to be spent on "National Priority Programs" in science, mathematics, computer, and foreign language education via the Secretary of Education's Discretionary Fund, and

"Carolyn S. Lee (cd.), "Exemplary Program Presentations, Title II of the Education for Economic Security Act, " mimeo prepared by the U.S. Department of Education for the December 1987 meeting of Title II coordinators, Washington, DC; and Carolyn S. Lee (cd.), "Exemplary Projects: Mathematics, Science, Computer Learning, and Foreign Languages: A Collection of Projects Funded Through Title II of the Education for Economic Security Act," mimeo prepared for December 1987 meeting of Title II Coordinators, Washington, DC.

"The following is based on the allocations that applied during fiscal years **1985 to 1988. They** have been amended somewhat in the recent reauthorization of the legislation.

Figure 6-l.—Distribution of Federal Funds Appropriated Under Title II of the Education for Economic Security Act of 1984



NOTE: Numbers in italics are final percentages of the original Department of Education 100% allocation; the numbers not Italicized are distribution formulas.

SOURCE: Office of Technology Assessment, 1988; based on data from the U.S. Department of Education.

the remaining 1 percent is divided **equally between the U.S. Territories and Insular Areas and the U.S. Bureau of Indian Affairs. Each State must submit a plan for the use of the funds to the Secretary of Education before the State's allocation can be released.**

The States' 90 percent allocation is divided among the States (including Puerto Rico and the District of Columbia) on the basis of the size of their school-age populations, with the proviso that each State must receive at least 0.5 percent of the total appropriation. Of the sum that each State receives, **30** percent must be given directly to the State's higher education agency (primarily for elementary and secondary teacher training programs), leaving **70** percent to be allocated by the State education agency for elementary and secondary education (no more than 5 percent of each of these allocations can be used for State administrative costs). Of the funds given to each State's education agency, **70** percent must be divided among the school districts, giving equal weight to the size of the total public and private school-age population and the number defined as "disadvantaged" under the Chapter 1 program of the Education Consolidation and Improvement Act of 1981. The 30 percent share of funds intended for elementary and secondary education that is retained by the State must be spent on exemplary programs in teacher training and instructional equipment, including those designed specifically to benefit the disadvantaged or the gifted, and on technical assistance to school districts.

Of the sum allocated to the Secretary's Discretionary Fund, 25 percent must be awarded to higher education for use in foreign language instruction improvement, and 75 percent must be spent on competitive awards for special programs. So far, two competitions for this fund have been held, awarding $5 million. In these competitions, special consideration must be given to magnet school programs for gifted and talented students and for historically underserved groups in science and engineering.

The net effect of the Title 11 legislation is to disperse appropriated funds very widely without consideration of whether dilution reaches a threshold where the funds make no discernible impact on **mathematics and science education. Almost all** school districts in the Nation have received small amounts of these funds; the problem is the size of the allocation. One-half of all the annual grants made to school districts under Title II were for less than $1,000 and one-quarter were for under **$250;** some districts have refused to apply for the funds, citing the desultory amounts of money that they would get as a result.[46] Most State Title II coordinators do not collect detailed data on the uses of these funds, but they believe that most are used for inservice training and workshops. Very little goes to support alternative certification and programs for training new teachers or teachers switching into science and/or mathematics.[47]

The legislation required States to justify their needs for this funding by providing needs assessments to the Department of Education, describing their plans for upgrading teacher quality in mathematics, science, computer learning, and foreign languages. Data yielded by these assessments have been of variable quality. CCSSO, with funding from NSF, did attempt to encourage States to report their data using common formulae and tabulations, and about 33 States (mainly the smaller States) supported this program. Congress required the Department of Education to provide it with a summary of the needs assessments *in* the fiscal **1986** NSF authorization (Public Law 99-1!59); the Department fulfilled this requirement in September 1987, although this document itself noted that it was of limited usefulness since the". . . resuiting needs assessment reports . . . are highly idiosyncratic and do not readily lend themselves to national generalizations ."[48]

[46]The evaluation of the distribution of funds under the program notes that one (unnamed) school district, which would receive ***$25*** under the program, was advised by its State Title II coordinator to discuss the district's inservice training needs for teachers over two and a half cases of beer.

[47]Ellen L. Marks, ***Title II of the Education for Economic Security Act: An Analysis of First-Year Operations*** (Washington, DC: Policy Studies Associates, October ***19$6).***

[48]Royce Dickens et al., "State Needs Assessments, Title 11 EESA: A Summary Report, " prepared for U.S. Department of Education, Office of Planning, Budget, and Evaluation, August 1987.

Data and Research Funded by the Department of Education and the National Science Foundation

The Federal Government, through NSF and the Department of Education, supports a great deal of data collection and analysis, as well as educational research and evaluation that is relevant to mathematics and science education. The following programs are active:

- Office of Studies and Program Assessment, NSF, providing data and management information on the national state of mathematics and science education;
- Program of Research in Teaching and Learning, NSF, funding educational research on effective teaching and learning in schools and universities;
- Center for Education Statistics, Office of Educational Research and Improvement (OERI), Department of Education, providing national data on education in all subjects; and
- research programs in OERI, funding educational research by individual investigators and centers, and its dissemination through research and development (R&D) centers and databases, such as ERIC.

The overall system of data collection on mathematics and science education would benefit from greater formal coordination between NSF and the Department of Education.[49] The best work has been done by NSF, particularly its two National Surveys of Mathematics and Science Education (in 1977 and 1985-86, respectively). But data on class enrollments by sex, race, and ethnicity are not available from the 1985-86 survey, and preliminary data on course-taking by high school graduates from the National Assessment of Educational Progress **1987** High School Transcript Study appeared late in 1987. A new Department of Education study, the National Educational Longitudinal Study, officially began in 1988. It would be valuable to have recent data to gauge the effects of educational reforms.[50]

Educational research in mathematics and science is in even more tenuous shape, however, having suffered (along with research in other subject areas) from budget cuts,[51] disputes among several relevant disciplines (including psychology and cognitive science), and a failure to pursue more active development programs as well as basic research.[52] In particular, education research in mathematics and science is still recovering from the shutdown of NSF's SEE Directorate in the early 1980s.[53] The key to better research, ultimately, will be better dissemination and development work that builds on the base of empirical knowledge. Data collection from States and school districts should be improved by changes enacted by Congress during the recent reauthorization of Federal education legislation.

The Department of Education also runs the National Diffusion Network (NDN), established in 1973, which disseminates and provides some funding for implementation of curricula that are of demonstrated educational benefit. NDN programs cover all levels of education, including higher education. By December 1987, there were 450 programs in NDN, and they were being used in about 20,000 schools with 2 million students. Ten of these programs were in science, four of which had originally been developed, in part or whole, with funds from NSF. Recent programs had been developed with Title II funds. NDN funds dissemination of programs, and the average grant is about **$50,000** over 4 years.[54]

[49] Informal coordination has been practiced for a long time, including joint National Science Foundation (Science and Engineering Education Directorate) -Department of Education review of educational research proposals (Richard Berry, former National Science Foundation staff, personal communication, August 1988).

[50] The Council of Chief State School Officers also coordinates various data collections by the States. Other Department of Education-funded longitudinal studies, the National Longitudinal Study and the High School and Beyond survey, have proved to be invaluable as well.

[51] U.S. Congress, General Accounting Office, ***Education Information: Changes in Funds and Priorities Have Affected Production and Quality,*** GAO/PEMD-88-4 (Washington, DC: U.S. Government Printing Office, November 1987).

[52] On research needs in science education generally, see Marcia C. Linn, "Establishing a Research Base for Science Education: Challenges, Trends, and Recommendations," ***Journal of Research in Science Teaching, vol. 24, No. 3, 1987,*** pp. 191-216.

[53] See Knapp et al., op. cit., footnote 5, vol. 2, pp. 1-27 to 1-50. For example, see National Science Foundation, ***Summary of Active Awards, Studies and Analyses Program*** (Washington, DC: March 1988).

[54] All data are from U.S. Department of Education, Office of Educational Research and Improvement, ***Science Education Pro-***

Education Programs in the Mission Research Agencies

Federal R&D mission agencies are active in mathematics and science education. The bulk of activity is in informal outreach programs, such as classroom visits, NASA's Spacemobile, laboratory open houses, career days, and science fairs. These programs touch tens of thousands of students—but only to a small degree. Some Federal laboratories "adopt" a high school, and thereby develop extensive contact with teachers and students. Adoption programs usually involve little or no direct cost to the agency, since they rely on employee volunteers to speak at schools, judge fairs, or host a visiting school group. Because these kinds of programs are informal in nature, they do not have established budgets or staff at the agency, and depend on the initiative of research staff as well as any education coordinators that the agency may have. They tend to wax and wane. Usually only a handful of people at any agency (including its field laboratories) work full time on education.

A few agencies also have modest programs to train and support mathematics and science teachers, ranging from summer research and refresher courses to resource centers where they can work with and copy instructional materials. None of the extensive teacher training workshops reach more than a few dozen teachers, however. One exception is NASA's interactive videoconferences on NASA's activities in space science education, which have drawn about **20,000** teachers each time.

The other genre of program is in research participation or apprenticeships, which reaches only a very few students but in much greater depth. These programs bring students, usually juniors or seniors in high school, into agency laboratories for research experience in ongoing mission R&D.

These research apprenticeships are powerful mechanisms. For example, since 1980, the NIH Minority High School Student Research Apprenticeship Program has awarded grants to universities and medical schools to bring students in for summer research projects. Students participate in all aspects of research; they collect data, review literature, attend seminars, use computers, and write up findings. In 1988, over 400 students will be supported on NIH grants totaling $1.5 million. At the program's peak in 1985-86, 1,000 students participated each summer. Over half the participants are Black; about 20 percent are Hispanic, another 20 percent Asian. Over half are female. Students are selected for aptitude and motivation, and on the recommendation of their science teacher.[55]

Mission agency summer research programs together support perhaps a few thousand high school students—certainly under 10,000—but, in any case, more than NSF's comparable program does. Full-fledged programs cost on the order of just under $1,000 to around $3,000 per student. Most of the cost is in salary for the student; there usually is significant cost-sharing with the host laboratory, and often with industry and other private supporters. Shorter summer programs, where students come in for a few weeks, or programs that mix hands-on research with instruction or career sessions, are less costly per student (up to a few hundred dollars); they also provide a less intensive experience.

Mission agency education activities, mostly local and informal, complement to a large extent the formal, research-oriented and nationwide programs of NSF. The mission agencies are particularly successful at reaching diverse populations. The programs build on the existing agency staff and facilities; many make special efforts to reach females and minorities. Formal minority research apprenticeships were established in 1979 by the Office of Science and Technology Policy for the major R&D agencies.

The mission agencies have unique strengths in reaching out to young science and mathematics

grams That Work: *A Collection of Proven Exemplary Educational Programs and Practices* in *the National Diffusion Network,* PIP 88-849 (Washington, DC: U.S. Government Printing Office, 1988).

[55] The National Institutes of Health evaluation testifies to the success of the research apprenticeships in encouraging participants to attend college and pursue a research career; 60 percent of students say that the experience influenced their career decisions. One of the touted strengths of the program is its flexibility and the institution's leeway in awarding and using the grants (the grants include salary for the apprentice, which may also be used for supplies or any relevant education activity). National Institutes of Health, personal communication, May 1988.

students. Federal research laboratories around the country are a particularly valuable resource for education, with unique facilities and equipment. DOE and NASA have large, visible laboratories doing state-of-the-art research in exciting areas such as space flight, lasers, the environment, and energy. Many of these laboratories are in areas where there is little or nothing else in the way of sophisticated research facilities. There is no place else students (or teachers) can see, touch, and work with equipment like rocket engines, whether it is for an afternoon visit or a summer of research. The thousands of researchers at these laboratories are likewise a valuable resource, offering inspiration, expertise on careers and nearly any special area of research, real-life role models for youngsters, and mentors for students doing research.

The ethos behind mission agency education efforts is to improve the quality and coverage of elementary and secondary education in their mission area, and ultimately to help ensure an adequate supply of scientists and engineers working both for the agency and in areas that support the agency's mission. (See table **6-4.)**

Major Mission Agency Programs

NASA is one of the most active and innovative mission agencies in education. Public education has been an integral part of NASA since its inception, and is a natural response to the continuing interest of children—and adults—in space science and exploration. The excitement of NASA's space mission clearly is an interesting way to package basic science and mathematics les-

Table 6-4.—Summary of Mission Agency K-12 Mathematics and Science Education Programs

Agency programs	FY 1988 budget	Number of students	Females/ minorities?
Summer research and enrichment:			
DOE High School Honors Research Program	$550,000	320	N
DOE Minority Student Research Apprenticeships	$120,000	200	Y
NIH Minority High School Student Research Apprenticeships	$1.5 M	410	Y
DoD Research in Engineering Apprenticeship			Y
DoD High School Apprenticeship (Office of Naval Research, Army Research Office, Air Force Office of Scientific Research)			Y
USDA Research Apprenticeship (Agricultural Research Service)	$250,000	200	
NASA Summer High School Research Apprenticeship Program		125	Y
General enrichment: [a]			
DOE Prefreshman Engineering Program	$300,000	2,000	Y
DoD/Army Computer-Related Science and Engineering Studies (4 weeks)	$50,000	60	
DoD UNITE		500-2,000	Y
NOAA D.C. Career Orientation	$30,000	24	Y
EPA summer internships			
USDA 4-H	$70-100 M	5 M	N
Teacher training and support:			
NASA education workshops	$1 M+	unknown	
NASA resource centers		unknown	
DOE research experience and institutes	**$250,000**	50	
USGS summer jobs for teachers	**unknown**	20-90	
Informal outreach: [b]			
All agencies (especially NASA and DoD); (also NIST, DOE, USDA, NOAA, USGS, EPA, NIH)		hundreds of thousands	

[a]Research, instruction, career orientation' usually short-term residential.
[b]Classroom visits and demonstrations, science fairs, talent searches, career fairs, laboratory open houses, weekend instruction and hands-on programs, partnerships ("adopt a school"), materials development and lending.

NOTE: Most programs include cost-sharing with host institution, and often with local industry and other sponsors.

KEY: DOE = Department of Energy
NIH = National Institutes of Health
USDA = US. Department of Agriculture
NASA = National Aeronautics and Space Administration
DoD = Department of Defense
NOAA = National Oceanic and Atmospheric Administration
EPA = Environmental Protection Agency
USGS = U.S. Geological Survey
NLST = National Institute of Standards and Technology

SOURCE: Office of Technology Assessment, 1988.

sons. An educational affairs division was formally created in 1986. NASA supports elementary and secondary teachers with workshops and resource materials at NASA's field centers. NASA is also reviewing and supplementing existing curricula, and has produced videotapes, satellite broadcasts, videodiscs, electronic tutors, and other innovative educational technologies. NASA has a summer high school apprenticeship, which employs about 125 students, most of them minority. In addition, about 30 full-time education outreach staff (mostly former teachers) spend over 160 days on the road with the Spacemobile (a mobile resource center for children about the space program), presenting school assemblies and class rooms.[56]

DOE, in cooperation with its national laboratories, has one of the most extensive programs for student summer research among the Federal agencies. It has several programs, for example, the high school honors research program (320 students, $550,000), and minority student research apprenticeships (200 students, $120,000). DOE brings in teachers, offering them research experience and training (in 1988, 50 teachers, $250,000). It is also building science education centers in its national laboratories as part of a university-laboratory cooperative program.

DOE and the Department of Defense (DoD) are the only agencies with substantial involvement in early engineering education. The prefreshman engineering program (PREP) awards money to universities to sponsor summer programs for females and minorities in junior high and high school. PREP programs include research experience, instruction, and career and college preparation. It reaches 2,000 students ($300,000), and benefits from substantial cost sharing and in-kind support.

Various offices of DoD support UNITE (Uninitiated Introduction to Engineering), which range from short stays to many-week research apprenticeships on engineering campuses. UNITE sessions include engineering and other technical classes, planning for college, career seminars, visits to military laboratories and facilities, and meetings with military engineers. Extensive followup of students shows that the program works. Students report that it helped shape their career goals; it turned some off, but it turned many more on to engineering. (UNITE is a military offshoot of programs sponsored by the Junior Engineering Technical Society, or JETS, a private organization with extensive corporate support. JETS coordinates Minority Introduction to Engineering programs to introduce students to engineering and college, most often as 1- or 2-week summer programs at universities.) The Research in Engineering Apprenticeship Program pays several hundred high school students to do mentored summer research at defense laboratories.

The National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, is a relatively small agency with few regional facilities. However, it does extensive informal outreach from its major laboratories in Maryland and Colorado. NIST encourages its research staff to give talks and demonstrations at schools, and work with science fairs and informal education programs.

USDA is surprisingly active in early science education. In particular, the well-established 4-H program, which has over 5 million participants in counties throughout the Nation, reaches an

[56]See National Aeronautics and Space Administration, "Educational Affairs Plan: A Five-Year Strategy, FY 1988 -1992," unpublished manuscript, October 1987.

Photo credit Children Television Workshop

There are many Federal programs which support innovation and research in science and mathematics education.

enormous number of children. USDA is launching an initiative to bring more basic science content into 4-H programs, involving such modern areas relevant to agricultural research as biotechnology and remote sensing. (See box 6-C.) They have received a small amount of funding from NSF to develop innovative science programs within 4-H. USDA also has many informal outreach and career programs. The Agricultural Research Service is the home for USDA's summer research apprentice program, which supports about **200** students each summer.

Within the Department of the Interior, the U.S. Geological Survey has extensive and well-organized elementary and secondary education programs. They also sponsor summer jobs for geology teachers. Other branches of the Department of the Interior have educational programs, mostly informal outreach. Much of the work of the Interior lends itself to summer internships for students.

Box 6-C.—4-H: Five Million Children

There are nearly 5 million children involved in 4-H, most under the age of 12.[1] The goals of 4-H are to teach children about agriculture and related sciences, increase technological and science literacy, and to interest children in agriculture and science careers.[2] 4-H is mounting a science and technology initiative that will broaden its scope to include the modern technologies and basic biological, physical, and chemical sciences that feed into agriculture. The core of 4-H is hands-on individual projects that allow children to learn by doing. Real-world applications include agriculture, food, nutrition, and soil science, from the more familiar growing gardens and raising goats to computer programming, space-based remote sensing, and molecular genetics. 4-H participants complete several projects a year that teach principles of the scientific method. Other media include instructional TV, science and agriculture fairs, visits to colleges and universities, and camps.

4-H draws upon a vast network of county extension agents, professionals, educators, and volunteers. This network is based in land-grant colleges and extension services. They support the over 600,000 volunteer leader-teachers who assist children in their projects. Many programs are in-school, involving teachers and clubs (4-H provides informal teacher training). Others are out of school with family, employer, and community support.

The national 4-H office is also sponsoring research into how children prepare for and choose agriculture and other science careers. This aims to promote positive attitudes toward science and technology, and helps 4-H design programs to encourage children to enroll in mathematics and science courses in high school, and later to enter science majors at universities (particularly, but not exclusively, agriculture-related majors at land-grant universities).

Money comes from the Cooperative Extension Service, jointly funded by Federal, State, and county governments. Total public funding for 4-H is about $260 million. The Federal contribution is probably about $70 to $100 million, although it is difficult to estimate because all Federal funds go into the general Cooperative Extention Service budget and cannot be distinguished by their end use. Industry and foundation contributions are on the order of $50 million. The estimated value of volunteer time is $1 billion.

[1]There are slightly more girls than boys, and just over 20 percent minority (16 percent Black, 1 percent American Indian, 4 percent Hispanic, and 2 percent Asian and Pacific Islanders).

[2]Allan Smith, U.S. Department of Agriculture, personal communication, February 1988; U.S. Department of Agriculture, Cooperative Extension Service, *Science and Technology: The 4-H Way, Status Report: 1986* (Washington, DC: U.S. Government Printing Office, May 1987); and U.S. Department of Agriculture, Cooperative Extension Service, *Annual 4-H Youth Development Enrollment Report, 1987 Fiscal Year* (Washington, DC: U.S. Government Printing Office, 1988).

RETHINKING THE FEDERAL ROLE IN MATHEMATICS AND SCIENCE EDUCATION

In thinking of any policy problem, it is useful to identify what goals a system is intended to meet, what alternative actions need to be weighed, and how those actions can be implemented to fulfill system goals. In the case of elementary and secondary mathematics and science education, it is the last of these that is the most difficult. What needs to be done is much more obvious than determining how it is to be done. The Federal Government is historically at least one step removed from those who have the most direct influence on teaching and learning-families, teachers, schools, and students. The Federal Government can and does provide incentives and support for some actions rather than others; rethinking the mechanisms of Federal support affects the larger issue of the division of roles nationally in education.

Mathematics and science education are part of a much larger set of issues with national dimensions; all, however, are built from the ground up: neighborhood schools, locally elected school boards, and State governments. The tension between national and local priorities has a long history, but is ultimately an essential part of the American system of participatory democracy. Reconciling national and local visions should be regarded as the job of educational policymaking, not an obstacle in its way.

Today, a new phase of Federal interest in education is developing. It is based on the need to train a better quality work force as well as the need to ensure equity of educational provision to all young Americans. The heightened importance of these needs will require change in several areas, including organizational arrangements in schools and school districts, the upgrading of the teacher work force, and, ultimately, new spending. The real cost of elementary and secondary education is already rising. More important, the need to improve mathematics and science course offerings, introduce more experimental work in classrooms, extend informal learning opportunities, and fuel enrichment programs both in and out of school cannot be met by improvements in the existing system alone. In particular, greater use will be made of both individual and collective learning styles in class and out.

The special challenge to formal mathematics and science education is its ability to command adequate, but not excessive, attention relative to the vast number of other issues that arise in elementary and secondary education.