# Chapter 2

# Elementary and Secondary Education: Shaping the Talent Pool

[large photograph in original manuscript omitted because of poor scan quality]

## CONTENTS

*Page*
Key Questions . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 23
Key Findings . . . . . . . ...**.. .... • ....*.. . . . . . . . . . . . . . . . . . . . . . . . . • .....,. , 23
Schools and Students. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . ..**.,. . . . . . 25
Formal Mathematics and Science Education . ., . . . ., ....;... . . . . . . . . . . . . . . . . 26
The Quality of Teaching . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 28
Tracking addability Grouping . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 30
Special School Environments . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 31
Student Career Plans . . . . . . . . .,*.*.** ..*.*... . . . ,..,.,, . . . . . . . . . . . . . . . . ,... 32
Informal Education and Intervention Programs . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 36
Opportunities for Federal Influence on the Talent Pool . . . . . . . . . . . . . . . . . . . . . . . . 40

### Boxes

***Box*** *Page*
2-A. The Unchanging Image of the Scientist, . . . . . . .; . . . . . . . . . . ; . . . . . . . . . . . . . *24*
2-B. The Scholastic Aptitude Test and the American College Testing Program . . . . 35
2-c. Characteristics of Intervention Programs That Work . . . . . . . . . . . . . . . . . . . . . . 38
2-D. Center for the Advancement of Academically Talented Youth, The Johns Hopkins University . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 39
2-E. The Mathematics, Engineering, Science Achievement Program . . . . . . . . . . . . . . 39
2-F. Urban Mathematics Collaborative . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 41

### Figures

*Figure* *Page*
2-I. Student Flows Into and Out of the Natural Science/Engineering Pipeline: The High School senior Class of 1972 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 32
2-2. Interest of College-Bound Students unnatural Science/Engineering, by Curriculum Track: 1982 High School Seniors . . . . . . . . . . . . . . ..... . . . . . . . . 34

### Tables

***Table*** *Page*
2-1. Comparison of Selected Mathematics and Science Course Offerings by School Grade Range, 1977 and 1985-88 . . . . . . . . . . . . . . . . . . . . . . ..*.,.. . . . . . . . . . . . . 27
2-2. Inservice Needs of Mathematics and Science Teachers . . . . ..**... . . . . . . . . . . . . 29

Chapter 2

# Elementary and Secondary Education: Shaping the Talent Pool

## KEY QUESTIONS

- What factors are associated with students' choices to major in science or engineering in college?
- What can schools do to interest, motivate, and prepare students for careers in science or engineering?
- What influences outside school have similar effects?
- What has prior Federal policy attempted to do and how successful has it been?

## KEY FINDINGS

- Mathematics preparation, hands-on laboratory and field experience, research participation, teachers' high expectations, high-quality teaching, and placement in the academic curriculum track or in a science-intensive school are correlated with interest in majoring in science or engineering in college.
- Career interests and expectations are also shaped by out-of-school experiences. Families are critically important influences.
- Elementary and secondary education as a whole needs renovation; mathematics and science are but one part of it. That huge system resists reforms. There are few incentives for teachers and schools to give most students the academic preparation required for a science or engineering career.
- Intervention programs, based both in the community and in the schools, can enrich children's experiences with and attitudes toward mathematics and science. Informal education in museums, science centers, summer camps, and community facilities may help remove barriers to learning.

The future supply of scientists and engineers depends, in the final analysis, on how well schools, families, and communities encourage children to study science and engineering. Many more students could emerge from high school interested in science and engineering, with good preparation in mathematics and science, than now do so. It is not easy, though, to identify what factors encourage students to prepare for science and engineering careers, or what factors deter them. (An attempt is made in chapter 1, table 1-1.) Students need interest, ability, and preparation in science and mathematics; none of these alone is sufficient. Students' social and economic standing, cultural traditions, sex, race, and ethnicity in turn shape their interest in science and engineering, their access to courses, and future educational opportunities. Many schools could do better jobs of encouraging students, of both sexes and of all ethnic backgrounds, to prepare for science and engineering careers. Other informal experiences, such as science centers and museums, educational television, and summer research programs, can also help generate interest.

In general, family, friends, and the media shape students' attitudes about careers in science and engineering. Unsupportive parents and friends or negative stereotypes of science can dim students' visions of such careers more surely than boring textbooks or teachers.[1] Researchers have documented the images of science that young students hold by asking them for written descriptions or drawings of scientists (see box 2-A). These results speak eloquently of the formidable task confronting a culture in continuing need of new scientists and engineers.

[1] Robert E. Fullilove, "Images of Science: Factors Affecting the Choice of Science as a Career," OTA contractor report, September 1987.

## Box 2-A.—The Unchanging Image of the Scientist

Children's ideas about scientists have changed little over the past 30 years. In 1957, Mead and Métraux summarized the views of about 35,000 high school students, noting consistently shared characteristics, and then a division between a positive and negative image:[1]

**Shared Image**

*The scientist is a man who wears a white coat and works in a laboratory. He is elderly or middle aged and wears glasses. . . . He may be bald. He may wear a beard, may be unshaven and unkempt. He may be stooped and tired. . . . He is surrounded by equipment: test tubes, bunsen burners, flasks and bottles, a jungle gym of blown glass tubes and weird machines with dials. . . . He spends his days doing experiments. He pours chemicals from one test tube into another. . . . He experiments with plants and animals, cutting them apart, injecting serum into animals. . . .*

**Positive Image**

*He is a very intelligent man–a genius. He has long years of expensive training. He is interested in his work and takes it seriously. He works for long hours in the laboratory, sometimes day and night, going without food and sleep. . . . He is prepared to work for years without getting results. One day he may straighten up and shout: "I've found it! I've found it!" . . . Through his work people will be healthier and live longer, they will have new and better products to make life easier and pleasanter at home, and our country will be protected from enemies abroad.*

**Negative Image**

*The scientist is a brain. He spends his days indoors, sitting in a laboratory, pouring things from one test tube into another. His work is uninteresting, dull, monotonous, tedious, time consuming. . . . He may live in a cold water flat . . . . His work may be dangerous. Chemicals may explode. He may be hurt by radiation or may die. If he does medical research, he may bring home disease, or may use himself as a guinea pig, or may even accidentally kill someone. . . . He is so involved with his work that he doesn't know what is going on in the world. He has no other interests and neglects his body for his mind. . . . He has no social life, no other intellectual interests, no hobbies or relaxations. He bores his wife. . . . He brings home work and also bugs and creepy things.*

(See page 42 for student drawings of scientists.)

Based on their analysis, Mead and Métraux suggested that the mass media should emphasize the real, human rewards of science, the enjoyment of group work, and how science works. Schools, they said, should:

- emphasize participation in the classroom rather than passive learning;
- emphasize group projects;
- teach science as immediately pertinent to human values, living things, and the natural world;
- teach mathematical principles much earlier;
- provide teachers who enjoy and are proficient in science;
- make sure that teaching and counseling encourage girls;
- de-emphasize the rare individual geniuses of science, such as Einstein, to make science more accessible to the average child and emphasize the individual sciences as broad fields of endeavor;
- avoid talking about "Science, Scientists, and The Scientific Method" as a whole, and rather, talk about individual fields and what different methods are; and
- emphasize life sciences, humans, and other living things to make science more immediate to children.

Children of the 1980s hold images of science and scientists that are essentially unchanged from those of the 1950s. In 1986, researchers at Harvard University's Educational Technology Center applied Mead and Métraux's methodology to another generation of potential scientists. They reported that:

*Most responses sounded familiar: scientists are nerds and science is important but boring. The students had little inkling of the day-to-day intellectual activities of scientists, of what experiments are for, or of the social nature of the scientific enterprise.*[2]

Also in 1986, Cheryl Mason investigated the source of students' images, based on drawings of scientists made by children using a "Draw-A-Scientist Test."[3] Two representative examples are shown below. Most drawings portray the familiar stereotype: the scientist is an elderly male, wearing a white coat and glasses and performing dangerous experiments. Interviews with 14- and 15-year-olds revealed that most students had developed impressions of science and scientists through movies and cartoons ". . . which depicted scientists as mad, antisocial men. "

Such images are potent and persistent. They enter into students' decisions about courses and careers. In part, these images reflect real characteristics of many scientists. To the extent that the stereotypes mask the diversity and ordinariness of many scientists, however, they may unduly deter children from pursuing science. Images are difficult to change. Teacher training is important; many students in Mason's study cited teachers' personalities and their teaching methods as reasons *for not liking science. Other approaches include exposure to a diversity of real-life scientists through field trips, guest presentations, and cooperative education and research work experience. Mead and Métraux's prescription still holds.*

[1] The following are direct quotes from Margaret Mead and Rhoda Metraux, *"Image of the Scientists Among High School Students," Science, vol. 126,* Aug. 30, 1957, pp. 384-390.

[2] *Harvard Education Letter,* "Why Do Few Students Want to Become Scientists?" vol. 4, No. 1, January 1988, p. 6.

[3] Cheryl L. Mason, Purdue University, "Student Attitudes Toward Science and Science-Related Careers: An Investigation of the Efficacy of a High School Biology Teacher Intervention Program," unpublished doctoral dissertation, 1986.

# SCHOOLS AND STUDENTS

Elementary and secondary education is a huge and varied enterprise in the United States, costing $170 billion per year, 4 percent of the gross national product. It uses 2.5 million teachers, takes place in more than 60,000 public and 40,000 private schools, and enrolls 45 million students. Public education takes place in 16,000 school districts and is the single greatest component of State spending. In 1984-85, States contributed about 49 percent of the cost of running public schools nationwide, while local authorities and the Federal Government provided 45 and 6 percent, respectively. It costs about $4,000 per year to educate a student.[2]

The quality of schools is crucial in determining the size and quality of the science and engineering talent pool. The tradition of local control, however, limits Federal influence over this stage in the preparation of potential scientists and engineers. The Constitution "reserves to the States and the people" many residual powers, including education. In turn, the States (except Hawaii) delegate this responsibility to localities. School districts and schools, within the general boundaries of State education standards, decide which mathematics and science courses will be offered. Teachers and guidance counselors, using standardized tests and individual judgments, decide which students will be encouraged to pursue courses leading to higher education in science or engineering and which, perhaps unwittingly, will be discouraged.

Many scientists and engineers say their career interest crystallized as early as elementary or junior high school, and most seem to make explicit choices before entry into high school. This has led to the widespread belief that future scientists and engineers select these majors early in life, then work hard and persist with their plans without considering other choices.[3] But new evidence suggests that many students' plans for their lives, as reflected in their intended college majors, change during high school.[4]

Preparing scientists and engineers is but one of many tasks that schools are asked to do. Instead of playing "talent scout" and encouraging those with the enthusiasm and ability to pursue science or engineering careers, schools too often see their function as culling out those who do not fit the traditional image of those destined for college and the professions by discouraging them from taking preparatory courses (including electives).[5] All capable students should feel welcome to study science and mathematics, not just those who believe they "need" such courses for their future careers.

[2] U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987 (Washington, DC: May 1987),* tables *3, 4, 5, 21, 59, and 93. Data are the most recent in each case, but are drawn from various years between 1980 and 1987.*

[3] *Historical evidence for this belief is collected in* Bernice T. Eiduson and Linda Beckman (eds.), *Science as a Career Choice (New York, NY: Russell Sage Foundation, 1973).*

[4] Valerie E. Lee, *"Identifying potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor* report, *September 1987.*

[5] *For example, see Mary Budd Rowe, "Getting Chemistry Off the Killer Course List," journal of Chemical Education, vol. 60, 1983,* pp. *954-956.*

School practices such as ability grouping or tracking are often applied too rigidly, restricting the preparation of students who would otherwise be capable of pursuing careers as scientists or engineers. Poor teaching, restricted course offerings, and dull or unrealistic mathematics and science curricula also discourage students. In many schools, students' coursework could be more wisely guided.[6]

In these ways, some American schools deprive able students of adequate preparation for science and engineering careers. The decentralized American school system resists change, so improvements are very difficult to propagate. Certainly, Federal policy options are limited in this sphere. State education standards are undergoing intense scrutiny and are being tightened.[7] Results will be slow to appear.[8]

## Formal Mathematics and Science Education

Many aspects of elementary and secondary school education in mathematics and science, such as overrigid tracking, poor curricula, and inadequate teaching, limit all students' opportunities and encouragements to major in science and engineering in college. For example, it is widely acknowledged that practical science experiments undertaken by students are an effective teaching method (and that students like them), but their role in high school science classes has declined somewhat during the last decade: lectures and discussions are more common.[9]

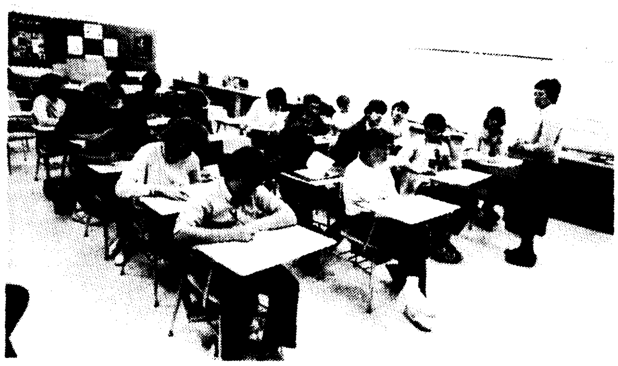


Photo credit: William Mills, Montgomery County Public Schools

Lectures and discussions are the most common teaching technique employed in mathematics and science classes. Too often, students emerge bored and alienated from science.

---

[6] Some argue that the democratic tradition of American education is sometimes observed most fully in the breach. The resulting lack of student preparation wastes talent. See P.A. Cusick, *The Egalitarian Ideal and the American High School* (New York, NY: Longman, 1983); Arthur G. Powell, *The Shopping Mall High School: Winners and Losers in the Educational Marketplace* (Boston, MA: Houghton Mifflin, 1985).

[7] Education Commission of the States, *Survey of State Initiatives to Improve Science and Mathematics Education* (Denver, CO: September 1987).

[8] There are some indicators of declining quality, particularly in achievement test scores. Data from the National Assessment of Educational Progress, a congressionally-mandated study of student achievement in several subject areas, for instance, show that the science achievement scores of 9-, 13-, and 17-year-old students have declined continuously since the first science assessment in 1969, although scores of 9- and 13-year-olds have risen somewhat since the mid-1970s. Mathematics achievement test scores of all age groups fell between 1972 and 1978, but, with the exception of 17-year-olds, these losses were recouped by 1982. See National Science Board, *Science Indicators: The 1985 Report* (Washington, DC: U.S. Government Printing Office, 1985), p. 125. The science assessments for 1969, 1972-73, and 1976-77 were conducted by the Education Commission of the States and are summarized in National Assessment of Educational Progress, *Three National Assessments of Science: Changes in Achievement, 1969-77* (Denver, CO: Education Commission of the States, June 1978). The science assessment for 1982 was, however, a special supplement conducted by the Science Assessment and Research Project at the University of Minnesota and was funded by the National Science Foundation (rather than the Department of Education). The assessment is summarized in Stacey J. Hueftle et al., *Images of Science: A Summary of Results From the 1981-82 National Assessment in Science* (Minneapolis, MN: Minnesota Research and Evaluation Center, 1983). For mathematics, see p. 126 of the National Science Board's *Science Indicators* (referenced above); National Assessment of Educational Progress, *The Third National Mathematics Assessment: Results, Trends, and Issues* (Denver, CO: Education Commission of the States, April 1983).

In addition, international comparisons–while difficult to interpret because of the great differences between the education systems of different nations—show that the achievement test scores of those U.S. students taking the traditional regimen of courses preparatory for science and engineering careers lag those of their peers in other developed nations, including Japan and Great Britain. See Curtis C. McKnight et al., *The Underachieving Curriculum: Assessing U.S. School Mathematics From an international Perspective* (Champaign, IL: Stipes Publishing Co., January 1987), pp. 22-30; F. Joe Crosswhite et al., *Second International Mathematics Study: Summary Report for the United States* (Washington, DC: National Center for Education Statistics, May 1985), pp. 4, 51, 61-68, and 70-74; Willard J. Jacobson et al., *The Second IEA Science Study-U. S.*, revised edition (New York, NY: Teachers College, Columbia University, September 1987); Robert Rothman, "Foreigners Outpace American Students in Science," *Education Week*, Apr. 29, 1987, p. 7; Wayne Riddle, *Comparison of the Achievement of American Elementary and Secondary Pupils With Those Abroad—The Examinations Sponsored by the International Association for the Evaluation of Educational Achievement*, 86-683 EPW (Washington, DC: Library of Congress, Congressional Research Service, Nov. 27, 1984, updated June 30, 1986). Declines in laboratory work in schools have also been attributed, for example, to its high expense and concerns about safety and liability.

[9] Iris R. Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education* (Research Triangle Park, NC: Research Triangle Institute, November 1987), table 25, p. 49.

**Table 2-1.—Comparison of Selected Mathematics and Science Course Offerings by School Grade Range, 1977 and 1985-86**

| | Percentage of schools offering course | | | |
|---|---|---|---|---|
| | Of all schools with at least grades 7-9[a] | | Of all schools with at least grades 10-12a | |
| Course title | 1977 | 1985-86 | 1977 | 1985-86 |
| *Mathematics:* | | | | |
| General mathematics, grade 9 | 36 | 33 | 59 | 64 |
| General mathematics, grades 10-12 | 17 | 42 | 46 | |
| Algebra, 1st year | — | 57 | — | 99 |
| Algebra, 2d year | — | 36 | — | 92 |
| Geometry | 33 | 41 | 97 | 95 |
| Trigonometry | 14 | 23 | 54 | 59 |
| Probability/statistics | 3 | 6 | 7 | 14 |
| Advanced senior mathematics, with no calculus | — | 12 | — | 36 |
| Advanced senior mathematics, with calculus | — | 12 | — | 34 |
| Calculus | 7 | 14 | 31 | 31 |
| Advanced placement calculus | — | 6 | — | 18 |
| *Science:* | | | | |
| Life science | 22 | 57 | 18 | 46 |
| Earth science | 28 | 57 | 37 | 52 |
| Physical science | 23 | 53 | 40 | 68 |
| General science, grade 7 | 65 | 43 | 23 | 25 |
| General science, grade 8 | 57 | 41 | 26 | 26 |
| General science, grade 9 | 21 | 17 | 46 | 31 |
| General science, grades 10-12 | 6 | 6 | 11 | 18 |
| Biology, 1st year | 30 | 41 | 95 | 99 |
| Chemistry, 1st year | 23 | 34 | 89 | 91 |
| Physics, 1st year | 22 | 32 | 78 | 81 |
| Biology, 2d year | — | 17 | — | 53 |
| Chemistry,2d year | — | 10 | — | 28 |
| Physics, 2d year | — | 4 | — | 11 |

[a]These schools may also contain higher or lower grades, respectively, but must at minimum cover the grade range specified.

SOURCE: Iris R. Weiss, *Report of the 1985-88 National Survey of Science and Mathematics* Education (Research Triangle Park, NC: Research Triangle institute, November 1987), tables 4 and 5.

In the Nation's schools, offerings of mathematics and science courses vary widely.[10] Many offer less than full ranges of college preparatory courses in mathematics and the sciences and a few have only very limited offerings. For example, data indicate that 81 percent offer at least 1 year of physics, but only 31 percent of high schools offer calculus (see table 2-l). There are also significant geographical differences in mathematics and science course offerings: schools in the West and Mountain States tend to offer fewer science and mathematics courses than those in other regions of the country, and rural schools offer fewer than urban ones.[11] The number and range of mathematics and science courses offered by schools, however, increased somewhat between 1977 and 1985 -86.[12]

Even when such courses are offered, enrollments are very low. Findings from a survey of 1982 high school graduates (the best available data on the courses that students actually take) suggested that less than 12 percent of students to whom calculus was offered, and less than 20 percent to whom

[10] Data about course *offerings and takings are very difficult to interpret because there is little consistency among analysts about the classification system to use in aggregating the huge variety of course titles that exist in schools. In addition, there is no guarantee that* two courses *of the same name have similar content.*

[11] *National* Center *for Education Statistics,* "Science and Mathematics Education in American High Schools: Results From the High School and Beyond Study," *bulletin, May 1984, pp. 16-2 1; Weiss, op. cit., footnote 9, table 6, p. 23.*

[12] *Weiss, op. cit., footnote 9, table 5, p. 21.*

physics was offered, took these courses.[13] The net effect is that few high school graduates have these course experiences. In 1982, 24 percent of high school graduates had taken chemistry, 11 percent physics, 7 percent trigonometry, and 6 percent calculus.[14] If more schools offered more college preparatory courses, enrollments in science and engineering would be expected to rise; increasing enrollments in existing courses is equally desirable.

Then there is the matter of course content. Some mathematics and science teachers cite the inadequacies of textbooks and concern about curricula in general.[15] In the 1960s, several efforts, many quite successful and federally funded, produced new classroom materials, especially in the sciences.[16] Less attention was paid to mathematics, however.

Now mathematics educators are pressing for better mathematics curricula and teaching. The mathematics research community, too, has been vigorous in its effort to reform the system of elementary, secondary, and undergraduate teaching of mathematics in the United States. The Mathematical Sciences Education Board was established under the auspices of the National Research Council in October 1985 to bring together mathematicians, mathematics educators, and representatives of school systems and local communities. The Board seeks to increase public understanding of school mathematics issues, formulate national goals for future mathematics teaching and learning, and plan ways to help States and school districts improve their curricula and performance in mathematics.

*Photo credit: William Mills, Montgomery County Public Schools*

Skilled mathematics and science teachers, especially in physics, are in short supply. Often, teachers qualified in other science or mathematics subjects are asked to teach such courses "out of field." Alternatively, schools may drop such courses altogether from their curricula.

## The Quality of Teaching

Teachers are critically important. Good ones can excite interest and promote both comprehension and perseverance; bad ones can stifle enthusiasm and mystify students. There are many very good teachers in American schools, but also many poor ones. The challenge is to attract good people to teaching, then provide the support to make them effective teachers who want to stay in the profession.

Some school districts find it difficult to recruit enough science and mathematics teachers. Most have difficulty finding high-quality teachers, especially for subjects such as physics. Consequently, many science and mathematics teachers must teach more than one subject, or what is known as "out of field" teaching. The underlying problem is the quality of teacher training. Most educators think the training that new science and mathematics teachers receive before beginning to teach should be improved.[17] For example, elementary school

[13] Evaluation Technologies Inc., *A Trend Study of High School Offerings and Enrollments: 1972-73 and 1981-82*, NCES 84-224 (Washington, DC: National Center for Education Statistics, December 1984), table 2.

[14] National Center for Education Statistics, Op. cit, footnote 11, pp. 16-21.

[15] Audrey B. Champagne and Leslie E. Hornig, "Critical Questions and Tentative Answers for the School Science Curriculum," *The Science Curriculum: The Report of the 1986 National Forum for School Science*, Audrey B. Champagne and Leslie E. Hornig (eds.) (Washington, DC: American Association for the Advancement of science, 1987), pp. 6-7.

[16] A comprehensive analysis of 81 different evaluation studies is reported in James A. Shymansky et al., "A Reassessment of the Effects of 60s Science Curricula on Student Performance," final report, mimeo, n.d. (a reworking of material originally published in 1983). This study found that, compared to control groups, students taking new curricula scored slightly higher on achievement tests, had more positive attitudes towards science, and exhibited smaller differences between the sexes in each of these attributes. Students taught by teachers who had been through preparatory teacher institutes scored higher than their peers taking the new curricula without this benefit. Patricia E. Blosser, "What Research Says: Research Related to Instructional Materials for Science," *School Science and Mathematics*, vol. 86, No. 6, October 1986, pp. 513-517; 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.

[17] Iris R. Weiss, "Pre- and Inservice Training, Roles of Various Actors, and Incentives to Quality Science Teaching," OTA workshop summary, September 1987.

teachers take little or no coursework in science and mathematics, yet are often expected to teach these subjects. In contrast, secondary school teachers often take respectable numbers of courses in science or mathematics, but these courses give them inaccurate images of what scientists do. Most of their science courses do not give them this information. Teachers strive to impart to students as much "content" as possible, neglecting time-consuming laboratory work and exercises in higher order thinking (which convey more of the reality of scientific work) in favor of lectures and tests of recall. There is very little consensus on what an improved college curriculum for future mathematics and science teachers should consist of, and little research is being conducted on this issue.

Mathematics and science teachers also need so-called inservice education to remedy gaps in their prior training and to update and broaden their knowledge. Table 2-2 lists current needs in inservice education. Although the amount of inservice education being offered by school districts is rising, it is still small. Anecdotal evidence suggests that, when such education is voluntary, only the most enthusiastic teachers (and presumably the best) participate, while those who need help the most are not reached. The Federal Government supports inservice education of teachers through the Department of Education and the National Science Foundation (NSF), but this funding has scattered impact.[18]

Training is only part of the picture. The whole environment in which teachers work constrains their enthusiasm. For example, systems of accountability, including teacher competency tests and checks on learning from lesson to lesson established by many States and school districts in recent years, may do more harm than good. By prescribing highly detailed lists of "objectives," course by course, school districts rob teachers of their professionalism by straitjacketing them into routines.[19] Given the

**Table 2-2.—Inservice Needs of Mathematics and Science Teachers**

- Remedies for inadequacies of existing teacher training programs.
- Updating of knowledge of developments in science and technology, and their uses.
- Improved understanding of generally applicable pedagogical techniques and those that reinforce equitable teaching practices.
- Updating of knowledge of teaching techniques that particularly apply to mathematics and science teaching.
- Updating of knowledge on effectiveness of and techniques for implementing developments in educational technology, such as computers, video, and CD-ROM.
- Opportunity to practice new teaching techniques and to share experiences with other teachers.

SOURCE: Office of Technology Assessment, 19S6.

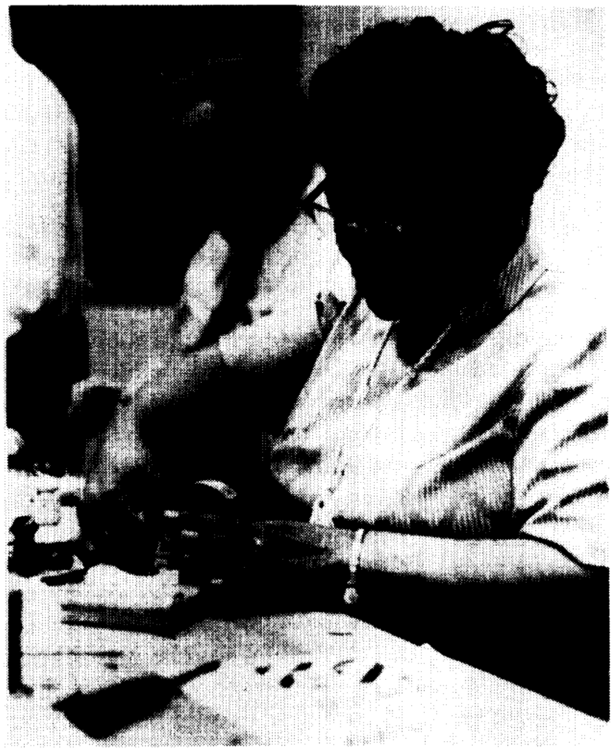


*Photo credit: Lawrence Hall of Science*

Teacher training (for those already certified and in the classroom) is conducted and funded by the States, school districts, foundations, industry, the Federal Government, and often by the teachers themselves. Still, many teachers either cannot or will not participate in such programs. Many successful science and mathematics teacher training programs are conducted at science centers and museums. Special emphasis is placed on hands-on experiments; this teacher is learning how one of these experiments works at the Lawrence Hall of Science, California, a science center that trains about 12,000 teachers per year.

[18]The *Federal Government spends about $110 million to $150 million per year (via Title 11 of the Education for Economic Security Act and the Teacher Preparation and Enhancement Program of the National Science Foundation's Science and Engineering Education Directorate) on teacher training. For details of the Title 11 program, see Ellen L. Marks, Title 11 of the Education for Economic Security Act: An Analysis of First-Year Operations (Washington, DC: Policy Studies Associates, October 1986).*

[19]Weiss, *op. cit., footnote 17.*

Photo credit: Katherine Lambert, National Science Teachers Association

The Presidential Awards for Excellence in Science and Mathematics Teaching, a program administered by the National Science Foundation and managed by the National Science Teachers Association, was established in 1983 to recognize outstanding public and private school teachers in all 50 States who can serve as models for their colleagues in science and mathematics teaching.

poor quality of some curricula, such as those for mathematics, course specifications may be a necessary evil, however.

In addition, the image of teaching in the United States could be better. This image is reinforced by modest salaries compared to those science and engineering graduates earn in industry and government. Salaries have risen by about 25 percent in real terms during the last 5 years, and States and taxpayers are beginning to demand evidence of the Positive effects of such increases. Qualified mathematics and science teachers are urgently needed, especially as role models for the growing minority student population.[20] Once in the classroom, excellent teachers must be retained. A number of ways of raising teachers' status and confidence could be tried. For example, teachers might be given increased opportunities for professional growth through short- or long-term sabbaticals and attendance at professional meetings, more time for class planning and less for noneducational duties (such as lunchroom supervision), and occasions to exchange ideas with other teachers via conferences and teacher centers (in their own schools and outside).[21]

## Tracking and Ability Grouping

Nearly universal in American schools, the practice of ability grouping—particularly in the form of curriculum "tracking"-is intended to make efficient use of teaching resources and allow students to move through curricula at rates appropriate to their abilities and interests. However, such grouping also has powerful disadvantages. Some suggest that students' assignment to tracks is often highly related to their race, ethnicity, and socioeconomic status, rather than to their ability per se.[22]

Grouping by ability in subjects such as reading and mathematics begins as early as third grade.[23] It is continued to high school, where students are generally distributed among academic (college preparatory), general, and vocational curriculum tracks; at this level, movement between tracks rarely occurs. But there is some evidence that the stranglehold of tracking is loosening: more students than ever are in the general track and not the academic track, while the pattern of courses that students take shows that they are increasingly mixing high-level mathematics courses with formerly vocational courses.[24]

When too rigidly applied, tracking can reduce opportunity by restricting access to advanced preparatory courses in mathematics and science. Despite the fact that students in the academic track are more

[20] Shirley M. McBay, *Increasing the Number and Quality of Minority Science and Mathematics Teachers* (New York, NY: Carnegie Forum on Education and the Economy, Task Force on Teaching as a Profession, January 1986).

[21] For a collection of perspectives, see *Educational Policy*, Special Issue on The Crisis in Teaching, vol. 1, No. 1, 1987, pp. 3-157. In October 1986, the 50,000-member National Science Teachers Association launched a teacher certification program. Early application requests suggest that there will be a huge response. The program is also aimed at influencing preservice teacher training. The National Council for Accreditation of Teacher Education is using National Science Teachers Association standards in accrediting science teaching programs in colleges and universities. See John Walsh, "Teacher Certification Program Under Way," *Science*, vol. 235, Feb. 20, 1987, pp. 838-839.

[22] Fullilove, op. cit., footnote 1; Jeannie Oakes, "Tracking: Can Schools Take a Different Route?" *NEA Today*, Special Issue, January 1988, pp. 41-47.

[23] Robert E. Slavin, "Ability Grouping and Student Achievement in Elementary Schools: A Best-Evidence Synthesis," U.S. Department of Education, Office of Educational Research and Improvement, Grant No. OERI-G-86-0006, June 1986.

[24] Evaluation Technologies Inc., *High School and Beyond: An Analysis of Course-Taking Patterns in Secondary Schools as Related to Student Characteristics* (Washington, DC: U.S. Department of Education, National Center for Education Statistics, March 1985).

likely to take these advanced courses than are their peers in the general and vocational tracks, 25 percent of college sophomores in 1984 who planned to major in natural science or engineering had been in these nonacademic tracks in high school.[25] While tracking can be useful in schools, it should not be used as an excuse for directing students away from courses they have the ability to master. Advanced mathematics and science courses are within the reach of more young Americans than currently take them.[26]

## Special School Environments

The ultimate extension of tracking and the demonstration of its potential benefits are schools that specialize in science and mathematics. There are three types of such schools:

- schools founded in the first part of the century when high schools were still a comparative rarity (such as the Bronx High School of Science in New York City);
- statewide schools (such as the School of Mathematics and Science in Durham, North Carolina); and
- magnet schools, which, although designed primarily to promote racial desegregation, can make important contributions to science education in cases of schools that take science and mathematics as their themes.[27]

These schools are often thought to be successful at winning converts to science and engineering careers, but there are no data to support or refute this contention; although many alumni do go on to science careers, it is to be expected that the students who enter such schools are more interested in science and mathematics than most. These schools are generally very popular with teachers and students, and are often oversubscribed. They are probably up to two or three times as expensive to operate as conventional schools.

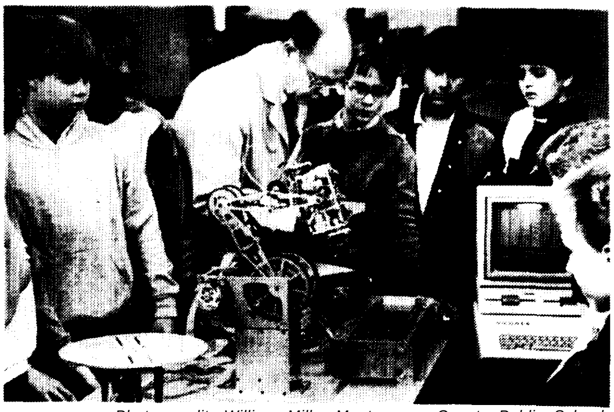


Photo credit: William Mills, Montgomery County Public Schools

Magnet schools, science-intensive schools, and other special school programs can give children the chance to work with sophisticated scientific equipment and topics. These programs can effectively stimulate interest in science and mathematics. However, schools and parents need to ensure that all students, regardless of sex, race, ability, or track, are given the opportunity and encouragement to explore science.

Issues similar to those raised by tracking are raised by special science schools. These issues include the possible draining of student and teaching talent from regular schools, and the diminution of curricular opportunities at regular schools. Whether special science schools have harmful effects seems to depend most on the specific political and organizational aspects of their implementation in each community. Some programs have been very controversial and have not done well, while others have been great successes. Almost always, the added choice given to parents and children by the opportunity to enroll in special science schools encourages communities to think about what they want from public education and to seek improvements from it.[28]

Magnet schools that specialize in mathematics and science also show some promising results for minority students. But since such schools are com-

[25] Lee, *op. cit., footnote 4.*

[26] Calculus, *in particular, has been hailed as the springboard to acquiring the analytical tools needed for success in a host of fields. Lynn A. Steen (cd.), Calculus for a New Century: A Pump, Not a Filter (Washington, DC: Mathematical Association of America, 1988). The number of calculus courses offered, in particular, is rising rapidly. But trigonometry and math analysis are the "priming courses" for the calculus "pump."*

[27] There are *in excess of 1,000 magnet schools at the moment, and their number is increasing. Probably about 25 percent of them adopt a mathematics or science theme. The most recent survey dates from 1983; Rolf K. Blank et al., Survey of Magnet Schools: Analyzing a Model for Quality Integrated Education (Washington, DC: James H. Lowry & Associates, September 1983.)*

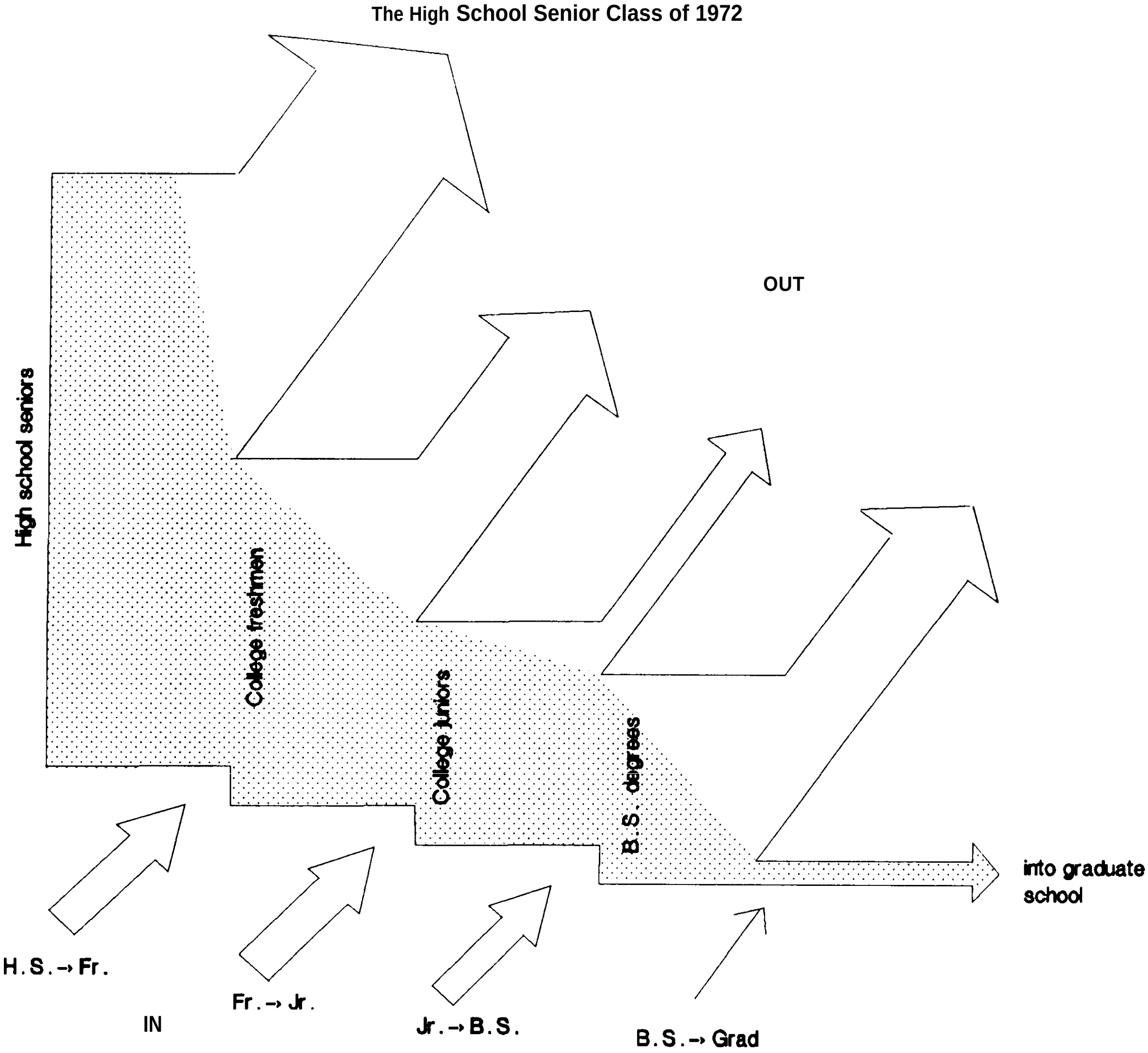
[28] Ibid.; *Education Week, "Call for Choice: Competition in the Educational Marketplace," vol. 6,* No. *39, June 24,* 1987.

monly designed to bring majority children into schools that are predominantly Black, sometimes minority children are more likely to be denied access to them, due to oversubscription, than are majority children. Apart from the desegregation rationale, elements of successful magnet schools could be replicated in schools of all kinds. Like all special school environments, magnets demonstrate the value of choice and diversity in American elementary and secondary education.

## Student Career Plans

Although schools, families, and friends help `determine students' career plans, such plans are, for most students, fairly volatile. As students are ex-

Figure 2-1 .- Student **Flows into and Out of the Natural Science/Engineering Pipelne**
**The High School Senior Class of 1972**




NOTE: Natural science/engineering includes physical, mathematical, and life sciences, and engineering, but not the social sciences. The width of the arrows reflects the number of students entering and leaving natural science/engineering at each stage. Among the 1972 high school seniors that plan to and do attend college, 13 percent are interested in natural science/engineering majors. Of this same college-bound cohort, by the first year of college 7.4 percent are interested in natural science/engineering; by college junior year, 4.8 percent; at college graduation, 4.6 percent; and only 0.8 percent enter graduate school in natural science/engineering.

SOURCE: Valerie E. Lea and Thomas L. Hilton, "Student Interest and Persistence in Science: Changes in the Educational Pipeline in the Last Decade," preprint, Feb. 10,1987.

posed to new ideas, teachers, and experiences, their thoughts turn to the future and particularly the connection between education and employment. Students planning to attend college take a variety of courses and are often well prepared for a number of different majors. According to most observers, the pool of students planning science or engineering majors is well formed by entry to high school, and only erodes thereafter. This is misleading. New evidence suggests that students join this pool, even up to their sophomore year in college (see figure 2-l).

At present, the number of college freshmen planning careers in science and engineering is declining even though overall freshman enrollment is holding steady. Although most universities are not yet complaining of "shortages, " student interest in science and engineering is waning, and interest in the physical sciences, mathematics, and engineering is falling faster than that in life and social sciences. There are also indications that a smaller proportion of the students with "A" or "A-" high school grade point averages ("high-achievers") now go on to major in science or engineering than in the past; many choose careers in business or law instead.[29]

To study how the science and engineering talent pool develops, OTA analyzed data from the U.S. Department of Education's "High School and Beyond" (HS&B) survey, which monitors two nationally representative samples, one drawn from those who in 1980 were high school sophomores. The survey contacts the same students every 2 years to collect data about their careers and educational progress.[30]

These students demonstrated considerable fluidity in their intended college majors as they progressed through the educational system. More than half of those interested in science and engineering as high school sophomores subsequently shifted to other subjects by their senior year. Others who had not named such majors as high school sophomores or seniors, in fact, were pursuing these majors as college sophomores. About 40 percent of those college sophomores planning science and engineering majors had indicated interest in conscience majors when they were high school seniors.[31]

While most college sophomores intending to pursue science and engineering have above-average high school achievement test scores, about 20 percent do not. Furthermore, about 25 percent of these sophomores were enrolled in the general and vocational (rather than the academic) curriculum tracks in high school (see figure 2-2). Those who switch preferences in favor of science and engineering have slightly lower average achievement test scores and have taken fewer mathematics and science courses than those who persist in interest in science and engineering. They are also more likely to be females and members of ethnic or racial minorities.

As many as 25 percent of all high school graduates, but only 15 percent of college sophomores, are interested in majoring in natural science and engineering. Among these fields, in both the sophomore and senior years of high school, the life and health sciences (which includes medicine and health careers) are the most popular, followed by engineering. A tiny number of students plan majors in the physical sciences and mathematics.

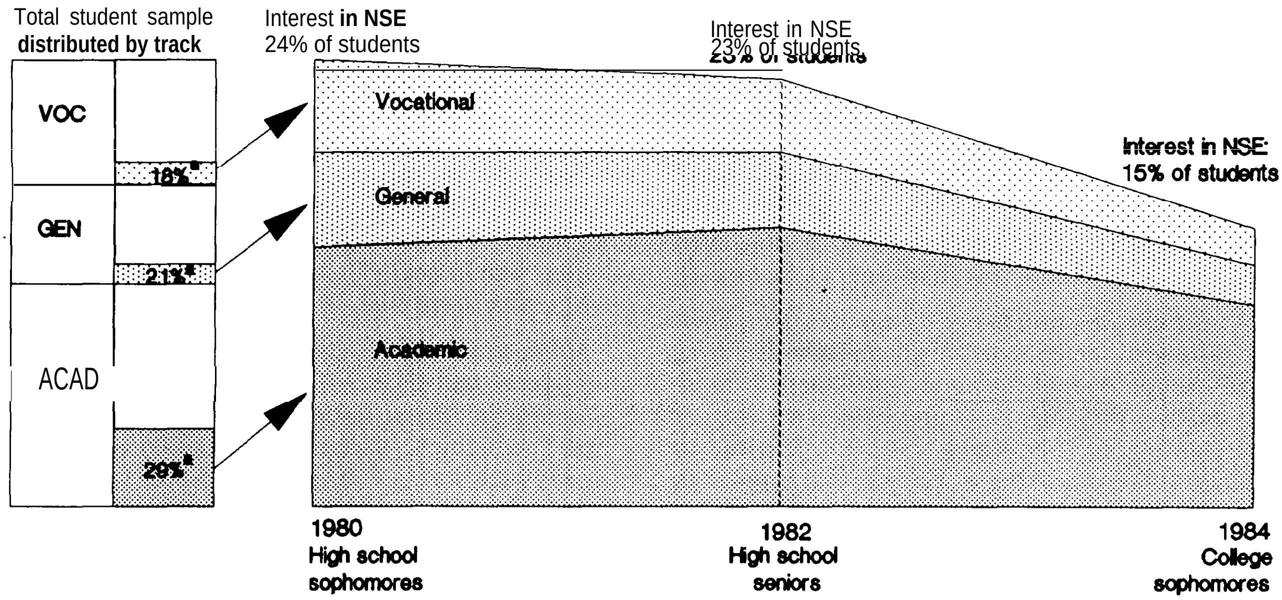
Smaller proportions of Blacks and Hispanics than whites are interested in science and engineering majors. But in fields such as medicine and health, the proportion of Blacks and Hispanics who say they are interested in these majors is similar to that of whites. There are prominent gender differences; more women than men favor the life and health sciences, while men dominate the group interested in engineering, the physical sciences, and mathematics.

[29] Kenneth C. Green, "Freshman Intentions and Science/Engineering Careers: A Longitudinal Analysis Based on the CIRP Freshman and Follow-Up Data," OTA contractor report, December 1987. Trends in students' career plans are discussed further in ch. 3.

[30] Of the two cohorts in the High School and Beyond survey, OTA chose the high school sophomores of 1980 for analysis of influences (during the final 2 years of high school) on students' orientation to science and engineering. The most recent followup data available to OTA were from 1984, at which stage many students in this sample were college sophomores. It is possible, therefore, that those interested in science and engineering did not ultimately complete baccalaureate programs. Data from the 1986 followup, which will allow analysis of the numbers of students in this cohort that actually persisted to college graduation in science and engineering, were released after conclusion of this analysis. See Lee, op. cit., footnote 4. Based on previous longitudinal analyses, it is likely that the majority of those who expressed interest in science in their college sophomore year did indeed go through with their plans. Still, attrition of students between college sophomore and senior years is significant.

[31] These and other findings reported below are based on Lee, op. cit., footnote 4. Some aspects of them are confirmed in independent analysis of the same data by Theodore C. Wagenaar, *Occupational Aspirations and Intended Field of Study in College*, NCES 84-217 (Washington, DC: National Center for Education Statistics, November 1984).

Figure 2-2. - Interest of College-bound Students in Natural Science/Engineering by Curriculum Track 1982 High School Seniors




[a]Percent of students in that track (who have not ruled out attending college) who are interested in natural science/engineering majors. Natural science/engineering does not Include the social sciences.

NOTE: Overall, Interest in natural science/engineering majors declines with time (24% of students in 1980, but only 15% in 1984 are interested in NSE). Students in the academic track are most likely to be interested in natural science/engineering majors and more likely to persist with their interest. At high school sophomore year, 60 percent of students interested in natural science/engineering majors were in the academic track; by sophomore year of college 74 percent were from the academic track. Student cohort of college-bound high school students is drawn from the High School and Beyond Survey of 1980 Sophomores.

SOURCE: Valerie E. Lee, OTA contractor report, 19S7.

Overall, fewer women than men are interested in science and engineering majors.

To examine further the underlying interest of Blacks and women in science and engineering, OTA analyzed their patterns of academic preparation (including course-taking) and socioeconomic status.[12] When course-taking, achievement test scores, and socioeconomic status are statistically held constant, Blacks are actually more likely than whites to be interested in majoring in science and engineering, and females are less likely than males to be interested. High school students of lower socioeconomic status are much less likely to plan science and engineering majors than are those of high socioeconomic status. Students of low socioeconomic status are less likely to be enrolled in the academic curriculum track. The effect of that track placement is to reduce the likelihood that they will. take advanced mathematics and science courses and maintain their interest in science and engineering careers.

Female participation in science and engineering may also be limited by an important "gateway" to college entrance: the mathematics portions of the Scholastic Aptitude Test (SAT) and of the Advanced College Testing (ACT) program. Several studies have shown that, even after controlling statistically for prior achievement test scores, course-taking patterns, and high school grades—women tend to get higher grades than men—women receive lower scores on these tests than men. Several observers argue that this discrepancy is due to bias in the tests' design and administration. Those responsible for the SAT and ACT argue, however, that the tests are not biased, and that differences in scores

[12]See, *for example, Gail E. Thomas, Center for Social Organization of Schools, Johns Hopkins University, "Determinants and Motivations Underlying the College Major Choice of Race and Sex Groups," March 1983;* K.R. *White, "The Relationship Between Socio-economic Status and Academic Achievement," Psychological Bulletin, vol. 91, 1982, pp. 461-481.*

are due to differences in student preparation and family background. " To the extent that bias may exist and that colleges and universities make no allowances for this deficiency of the SAT and ACT, women may be deterred from science and engineering careers (see box 2-B).

[33] In *the absence of a national high school curriculum, standardized test scores have historically been a key measure that assists college* admissions offices in *their decisionmaking.* How *college admissions officers* weigh *(or do not* use at *all) these scores relative* to *ocher factors is the* overriding *issue* in *the standardized testing controversy. A.M.* Pallas *and* K.A. *Alexander, "Sex Differences in Quantitative SAT* Performance: New Evidence on the *Differential* Coursework *Hypothesis," American Educational Research Journal, vol. 20, No. 2, 1983, pp. 165- 182;* Thomas F. Donlon (cd.), *The College Board Technical Handbook for the Scholastic Aptitude Test and Achievement Tests (New York:* College *Entrance Examination Board,* 1984), chs. *7 and 8; and Phyllis* Rosser, *"Girls,* Boys, *and the SAT: Can We Even* the Score?" *NEA Today, Special Edition, January 1988, pp. 48-53.*

## **Box** 2-B.—The Scholastic Aptitude Test and the American College Testing Program

Most college applicants take either one or both of these tests in their senior or junior year of high school in order to satisfy the admissions procedures of most selective colleges.[1] In 1987, just over one million students took the Scholastic Aptitude Test (SAT) and three-quarters of a million the American college Testing Program (ACT), respectively about 40 and 30 percent of the high school graduating class.[2] The ACT is traditionally taken in the Western, Midwestern, and Southern States, whereas the SAT is traditionally taken in the Eastern States and on the west coast.[3]

**The Scholastic Aptitude Test.**–The SAT is administered by the College Board, a nonprofit membership organization funded by more than 2,500 colleges, schools, school systems, and education associations. The test itself is developed, conducted, and scored by the Educational Testing Service, Inc., of Princeton, New Jersey, which is an independent, nonprofit organization dedicated to testing.

The SAT is designed to predict how well students will do academically during their college freshman year by measuring those developed verbal and mathematical reasoning abilities that the College Board believes are most closely related to successful college performance. The College Board does recommend, however, that other information, such as students' course transcripts, interests, and extracurricular activities should also be taken into account.[4] Nevertheless, the material that the SAT covers will not necessarily have been taught in all schools, and some of it relates to those reasoning, deductive, logical, and verbal abilities that students only acquire indirectly.

The results of the SAT are two scores: one for verbal reasoning ability and the other for mathematical reasoning ability. Performance on both parts of the test together is reported on a standardized scale from 200 to 800 points, and the College Board says that the error of measurement in any student's score is approximately 30 to **40** points.

The most controversial aspect of the SAT is the extent to which it appears to discriminate against females and minorities. In successive years of testing, both males and females score about equally on the verbal portion of the test, but on the mathematics portion males score 50 points higher than females. Blacks, on average, score 50 to 80 points lower than the entire population on each half of the test. Hispanics, on average, also score poorly, but higher than Blacks. Black and Hispanic scores have increased considerably during the last decade, by about 20 and 10 points, respectively, whereas the average score earned by the entire test-taking population each year has increased by only about 3 points. The 1987 scores, by race/ethnic group, are shown below.

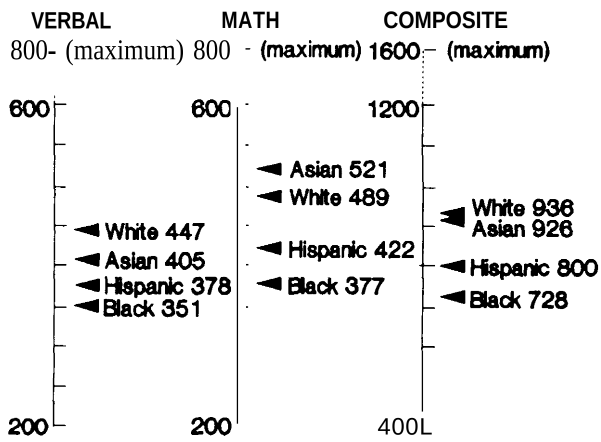
Changes in SAT test scores have sometimes been quoted as indicators of the health and productivity of the American education system. They have only limited usefulness for this purpose, however, because the tests are designed only to predict students' first-year performance in college, and because the characteristics of the students who take the test differ from year to year and State to State,

**The American College Testing Program.—The** American College Testing Program is an independent, nonprofit organization that administers the ACT Assessment Program, a comprehensive service designed to aid both college applicants and admissions offices. The American College Testing Program is governed by the ACT Corp., composed of elected representatives from the States that make the most use of the test and from the ACT Board of Trustees.

The heart of the ACT Assessment Program is a series of tests: English usage, mathematics usage, social studies reading, and natural sciences reading. The tests are designed to predict college performance. The results of the program are considerably more complicated than those of the SAT. They include the student's scores on these tests, comparisons of these scores with those received by previous freshmen at each institution that the student applies to, comparisons with the scores received by freshmen at comparable institutions nationally, predictions of future performance, records of the student's high school courses and grades, indications of career interests, and indications of special remedial work that the student might benefit from. Scores on the 4 tests are normalized to a common scale ranging from 1 to 36 points, with a standard error of measurement of 1 to 2 points and a mean for all college-bound students of 18 points.

Females score lower on the ACT Assessment than do males. Overall, their scores are about 1.5 points lower, and, in the case of the mathematics test, females score about 2.5 points lower. Nevertheless, the mean high school grades of female ACT Assessment takers is greater than that of males.

**SAT Scores By Race/Ethnicity , 1987**




**SOURCE: The College Board, 1987** *Profile of SAT and Achievement Test Takers, 1987,* **p. v; data from Educational Testing Service.**

[1] A small, but increasing, number of colleges do not require such test scores for admission. See National Center for Fair and Open Testing, *Beyond Standardized Tests: Admissions Alternatives That Work* (Cambridge, MA: FairTest, 1987).

[2] U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: May 1987), table 71. Data for the number of high school graduates are for 1984-85.

[3] *The Chronicle of Higher Education,* Sept. 30, 1987, p. 34. For example, in 1982, 66 percent of all high school graduates in Massachusetts took the SAT, whereas only 3 percent of those in Iowa, Mississippi, North Dakota, and South Dakota did.

[4] College Entrance Examination Board, *College Bound Seniors: 1987 Profile of SA T and Achievement Test Takers* (New York, NY: College Entrance Examination Board, 1987). Thomas F. Da-don (d.), *The College Board Technical Handbook for the Scholastic Aptitude Tesr and Achievement Tests* (New York, NY: College Entrance Examination Board, 1984), chs. 7 and 8.

# INFORMAL EDUCATION AND INTERVENTION PROGRAMS

Although impossible to quantify, influences of families, friends, the media, and other aspects of the society on students are probably as great as those of the schools. The out-of-school environment offers opportunities to enhance students' appreciation of science and mathematics or to give them "second chances" in these areas, regardless of test-determined abilities. Programs outside of school can be both alternatives and complements to school activities. In some cases, successful informal education and intervention programs can impel communities to call for changes in curricula, course offerings, or the use of technology in the schools.

Some students are intimidated by science. Nonschool and community-based programs, including science centers and museums, can awaken interest for these students, without raising the spectre of failure."[34] (As Frank Oppenheimer, founder of San Francisco's famed Exploratorium, noted, "Nobody flunks a museum.") The number of science centers and museums is steadily increasing. A recent survey identified 150 in the United States, with 45 million visitors in 1986, up from 33 million in 1979. Half of these visitors were under 18 years of age. Science centers are also active in mathematics and science teacher training. In 1986, more than 65,000 teachers participated in such programs.[35]

[34] Association of Science–Technology Centers, *Natural Partners: How Science Centers and Community Groups Can Team up to Increase Science Literacy* (Washington, DC: July 1987); George W. Tressel, "The Role of Museums in Science Education," *Science Education,* vol. 64, No. 2, 1980, pp. 257-260.

[35] These estimates are from the Association of Science-Technology Centers, Basic Science Center Data Survey 1988, unpublished data, February 1988. It is important to note that the majority of funding for science centers comes from local sources and admissions charges,

*Photo credit: Nancy Rodger, Exploratorium, San Francisco*

**Science centers can provide an informal, welcoming environment for families, children, adults, and teachers to learn about science in a way different from that in the classroom. The Exploratorium has more than 400 exhibits that people of all ages can see, touch, hear, and manipulate directly. Many exhibits are attended by "Explainers," local junior high and high school students trained to answer questions and provoke curiosity about the scientific principles illustrated by the exhibit.**

Science centers and other nonschool programs can open new avenues of career opportunity; for others, they enrich interests already formed. The Children's Television Workshop's 3-2-1 *Contact* series is designed to interest students from 8 to 12 years old in science. Broadcast on many public television stations, it is generally regarded favorably, although data on its effects are sparse. The series is watched at least occasionally by about one-quarter of all households with children under 11 years old.[36]

A particular niche for informal science education programs is in promoting the science and mathematics interests of female and minority children. These "intervention programs" began in the 1960s and became popular in the 1970s when they attracted Federal funds. Such programs vary widely in longevity, sources of support, goals, and quality. They are often based in universities, museums, and research centers, as well as churches, community organizations, and businesses. Today, most are local initiatives funded by foundations, industry, and States. Many achieve a good deal of success from limited resources (see box 2-C).

A study by the American Association for the Advancement of Science notes that early, sustained applications of excellent instruction can bring minority achievement to the same level as that of white males.[37] Indeed, some suggest that the techniques applied by intervention programs, such as hands-on experiments and other activities conducted in

*Excluding three centers operated directly by the Federal Government, an average of 2 percent of science center funding comes from Federal sources.*

"*Research Communications, Ltd., "An Exploratory Study of 3-2-1 Contact* Viewership," *National Science Foundation contractor report, June 1987.*

[37]Shirley *M.* Malcom *et al., Equity and Excellence: Compatible Goals, Publication 84-14 (Washington, DC: American Association for the Advancement of Science, December* 1984).

## Box 2-C.—Characteristics of Intervention Programs That Work

Over the past 10 to 20 years, special programs have been used to encourage children's interest and proficiency in academics and especially in science and engineering. Programs have worked in school and out of school, with students of all ages, cultures, and races; with youngsters of exceptional mathematics and academic achievement and with high school dropouts; in fields from agriculture to engineering. Some programs use professional experts and the latest in testing and computer technologies; others work on shoestring budgets with egg cartons and volunteers. From these experiences, both successes and failures, have emerged lessons about what makes an intervention program work. The characteristics of successful intervention programs are listed below:

- clearly defined educational goals,
- high expectations among teachers and leaders,
- committed leadership,
- role models to motivate students,
- peer support with critical mass of students,
- student commitment and investment (increased study time),
- hands-on laboratory experience,
- assessment and feedback to students!
- specific goals for minorities or women,
- recruitment,
- financial aid (fellowships and traineeships augmented by research assistantships),
- multi-year involvement with students, and
- program evaluation based on student achievement,

SOURCES: Office of Technology Assessment, 1988; Government-University-Industry Research Roundtable, *Nurturing Science and Engineering Talent* (Washington, DC: National Academy of Sciences, July 1987), pp. 36-38.

small groups (see box 2-D), could usefully be disseminated to the entire school-age population.

Most programs also require extraordinary staff commitment and support, which are not easy to replicate from location to location. However, the Mathematics, Engineering, and Science Achievement (MESA) program, founded in the San Francisco Bay area in 1970, expanded throughout California and has been successfully transferred to other States (see box 2-E). Today MESA offers a model adaptable to students in junior high school through college.

Intervention programs do, however, pose a dilemma to schools and school districts. Ideally, schooling would adapt to and cultivate each student's unique aptitudes and interests, and be equally excellent nationwide. That long-term goal will not soon be reached. In the meantime, some commentators suggest that intervention programs outside schools are vital because the schools themselves are so impervious to reforms designed to improve the progress of students disaffected from science. Others feel that intervention programs can work well in schools. Some school districts, therefore, have welcomed intervention programs, while others have regarded them with some suspicion.

It is not clear why females and members of some racial and ethnic minority groups, on average, begin to fall behind in mathematics and science preparation as early as elementary school, and are less likely than white males to persist in science and engineering. But intervention programs can help reduce These differences by instilling confidence and increasing motivation—attitudes not easily measured. Intervention programs effectively encourage women

Photo credit: William Mills, Montgomery County Public Schools

Parents can help their children to prepare for school work in mathematics and science from an early age. But many parents lack the confidence in these subjects to encourage their children. Programs such as "Family Math," devised at the Lawrence Hail of Science, California, are designed for both parents and children to use together. The program has expanded to many cities around the Nation.

**Box 20D.–Center for the Advancement of Academically Talented Youth, The Johns Hopkins University**

The Center for the Advancement of Academically Talented Youth (CTY) has gained an international reputation for identifying and furthering the education of mathematically and verbally talented students at the junior and senior high school levels. Dr. Julian Stanley founded the Study of Mathematically Precocious Youth in 1971 to identify mathematically talented adolescents. CTY's Regional, National, and International Talent Searches have identified more than 70,000 highly able students since its inception in 1979. Most of the CTY programs, which are designed for 12- to 16-year-olds, are held during the summer months, although Expository Writing and Science/Mathematics Tutorials-By-Mail are available to participants during the academic year,

CTY relies on standardized tests, particularly the Scholastic Aptitude Test, to identify youngsters for its programs. For many high-talent students, CTY claims, the program is the first opportunity to match their learning with their ability, While participation in CTY programs can result in early college admission for some, the principal aim is to enrich the preparation of students. CTY classes are demanding and span the humanities, mathematics, computer science, and the natural sciences. To provide students with individualized instruction that caters to their differing ability levels, the program matches participants with instructors in one-to-one exchanges at various points during the course. CTY also helps students negotiate with their home schools for appropriate course placement and credit for CTY work. Letter grades courses are not given unless specifically requested by the student's school. Nevertheless, upon completion of the program, CTY does provide each student with a detailed description of his or her performance, and all students take the College Board Achievement Test in the appropriate subject area, In addition, CTY does offer some college scholarships for outstanding students.

CTY conducts extensive followups on its participants. In 1986, three groups of former participants were asked to describe their current educational and career development. More than 90 percent were then attending college. Many responded in essay form about their CTY experience; one student wrote in her evaluation of classes: "There is a feeling that I can't find anywhere else in the world . . . . I will miss CTY. It is here that I am most alive." Students feel comfortable and exercise their full potential in an informal environment which, given the ages of students, can be as important to their development as is academic preparation. The same student noted, "At CTY, I belonged. I felt better about myself than I had since I entered junior high school. "

**Box 20-E.—The Mathematics, Engineering, Science Achievement Program**

The Mathematics, Engineering, Science Achievement (MESA) program, begun in 1970 and based at the Lawrence Hall of Science in Berkeley, California, aims to increase the number of Black, Hispanic, and Native American students in California that complete 4-year university degrees in mathematics, science, or engineering. The program operates under the auspices of the University of California at Berkeley.

Working with junior high and high school students as well as undergraduates, the MESA Program has proven effective at recruiting and retaining minority students in these fields. MESA is widely acclaimed, and has been replicated in other States, including Colorado, New Mexico, Washington, Oregon, Kansas, and Utah. Activities offered by the program include internships, field trips, incentive awards, counseling, college freshman orientation and guidance, financial aid and scholarships, and the formation of student study groups to foster cooperative learning. The program reached 7,800 students in 1985-86 and operated in one-quarter of all California high schools with a predominantly minority enrollment. Most of the high school graduates who have participated in MESA programs have gone on to mathematics-based majors.

The MESA Program offers a Minority Engineering Program (MEP) and a Pre-College Program. The former operates through about 15 centers, most on campuses of the California State University and the University of California, and in 1985 -86,1 served about 2,500 students. The latter operates in 17 centers, also mainly on college campuses, and served over 5,000 students drawn from 60 school districts, A particular emphasis of the Pre-College Program is encouraging students to take the optional preparatory series of classes in mathematics and science in junior high and high schools, which are very difficult to make up once a student has missed them.

Most of the MESA Program's funds ($2.34 million) have come from the State of California, and other sources have been over 40 corporations and foundations, including a $610,000 3-year grant from the Carnegie Corp. MESA also operates programs for junior high and high school teachers (more than 200 attended workshops on hands-on teaching methods in mathematics and science in 1985-86), and has close links with other intervention programs, such as the University of California at Berkeley's Professional Development Program, EQUALS, and the South East Consortium for Minorities in Engineering.

The effectiveness of MESA's MEP is indicated by the retention rates of its participants. For example, 60 percent of MEP freshmen, after 3 years, remain in college, compared with 47 percent of all students. In engineering, Black and Hispanic MEP students have retention rates of 64 percent and 57 percent, respectively, after 2 years (compared with 13 percent and 21 percent for Black and Hispanic nonparticipants).[2]

[1]All data reported below are for 1985-86.

[2]These data are for University of California students only, though statistics from the California State University system are similar. "Retention rate" is percent enrolled at the university after 2 or 3 years of study. California Postsecondary Education Commission, *Retention of Students in Engineering, A* Report to the Legislature in Response to Senate Concurrent Resolution 16, 1985 (Sacramento, CA: December 1986).

and minorities to consider science and engineering careers. The techniques used by these programs would also be effective with the general population of students. Institutionalizing intervention techniques in the schools, without robbing them of their appeal, would seem promising. Such institutionalization would depend on training teachers to use intervention techniques in classrooms.

In the decentralized American education system, even the most successful programs are extremely difficult to replicate. The inherent conservatism of local school authorities is one impediment. Another is the difficulty of generating the community and family support necessary to recruit students and maintain programs' momentum. The fundamental problem is that special intervention programs should not be necessary. That they are, some argue, is an indictment of America's education system, which has fallen short of fulfilling the democratic ideals of equal opportunity and of schools as centers of learning.

## OPPORTUNITIES FOR FEDERAL INFLUENCE ON THE TALENT POOL

The Federal Government has only a modest influence on elementary and secondary mathematics and science education. If public education is the collective responsibility of the States and the school districts (which together bear most of its cost), then school districts and States must both examine what they can do to improve science and mathematics experiences for all of their students and address the specific problems that inhibit the development of scientific and engineering talent.

The Federal Government in the past has made attempts, with some success, to improve mathematics and science education in the schools. The lead agency for Federal intervention in school mathematics and science education has been the National Science Foundation. Although NSF has been interested principally in students who are most likely to become scientists and engineers, there are now renewed calls for NSF to take a more comprehensive approach and "broaden the base" of students learning science.[38] In fiscal year 1988, NSF's total precollege effort is funded at about $90 million, all of it through the Science and Engineering Education Directorate.

Following the so-called Sputnik Crisis, Congress passed the National Defense Education Act of 1958,

[38]Michael S. Knapp et al., *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation* (Menlo Park, CA: SRI International, June 1987). Congress ordered the National Science Foundation to commission this study of the areas in which the National Science Foundation, given its strengths and weaknesses, could best intervene in school mathematics and science education.

which provided extensive funding to school districts for science equipment, supplies, and teacher training. In the early 1960s, Congress also increased funding of NSF's science education activities until, at its peak, about half of NSF's budget went to education and the bulk of that to its popular program of teacher training institutes. Data suggest that, in those years, about half of all high school mathematics and science teachers attended at least one such institute. A small program of similar activities is still funded by NSF.[39]

NSF's teacher institutes were designed to bring teachers up-to-date with advances in science and were very popular. Many teachers, supervisors, and leaders of the science education community fondly remember these programs as bringing an espirit de corps to the teaching profession, and updating teachers' scientific knowledge, particularly in experimental work. However, since attendance at the institutes was voluntary, many teachers (often the least interested and least well qualified) shunned them. The effectiveness of the institutes has been debated, both because of the difficulty of defining and researching the effectiveness of any teacher improvement program and because the institutes were not systematically evaluated at the time.[40] Any future replication of the institutes program would be costly, and it might require $500 million to $1 billion, spread over several years, to put all existing secondary mathematics and science teachers through at least one institute program. But a second generation of institutes would likely remedy past mistakes and benefit from successful teacher improvement activities that have been funded by school districts and foundations (for example, see box 2-F).[41]

Renewed concern about the state of mathematics and science education in the schools led Congress to pass the Education for Economic Security Act of 1984, which has provided $40 million to $140 million annually, mainly for teacher training and educational activities.[42] The Federal Government, via

*[39] The National Science Foundation remains cautious and makes no claims either for the institutes' effectiveness or ineffectiveness. But many science educators think that the institutes were remarkably successful. A study by the Congressional Research Service in 1975 found that the institutes were of great value. U.S. Congress, Congressional Research Service,* The National Science Foundation and Pre-College Science Education: 1950-1975 *(Washington, DC: U.S. House of Representatives, Committee on Science and Technology, Subcommittee on Science, Research, and Technology, January 1976), Committee print. Hillier Krieghbaum and Hugh Rawsom,* An Investment in Knowledge *(New York, NY: New York University Press, 1969) suggest that the institutes were effective. 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, found some modest positive effects. Also see Knapp et al., op. cit., footnote 38, vol. 1, p. 130.*

*[40] The General Accounting Office reviewed research on the National Science Foundation-funded institutes and found little or no evidence that such institutes had improved student achievement scores. U.S. General Accounting Office,* New Directions for Federal Programs To Aid Mathematics and Science Teaching, *GAO/PEMD-84-5 (Washington, DC: Mar. 6, 1984).*

*[41] The National Science Foundation has also funded curriculum development efforts and informal education activities, such as educational television and science centers, with some success.*

[42] Marks, *op. cit., footnote 18.*

**Box 2-F.–Urban Mathematics Collaborative**

This innovative program is designed to support and reinvigorate mathematics teachers in 11 inner. city centers. Each mathematics collaborative brings together a community-wide advisory board of teachers and business, civic, and university leaders, with a part-time administrative staff. Collaborative currently exist in Cleveland, Los Angeles, Minneapolis/St. Paul, Philadelphia, San Francisco, Durham, Memphis, New Orleans, Pittsburgh, San Diego, and St. Louis. The program was started with a Ford Foundation grant in 1984. To date, the foundation has committed over $2 million. Each collaborative receives Ford Foundation support for 3 to 5 years in the expectation that each will become a self-sustaining program funded by community businesses, industries, colleges, universities, and other civic and cultural organizations.

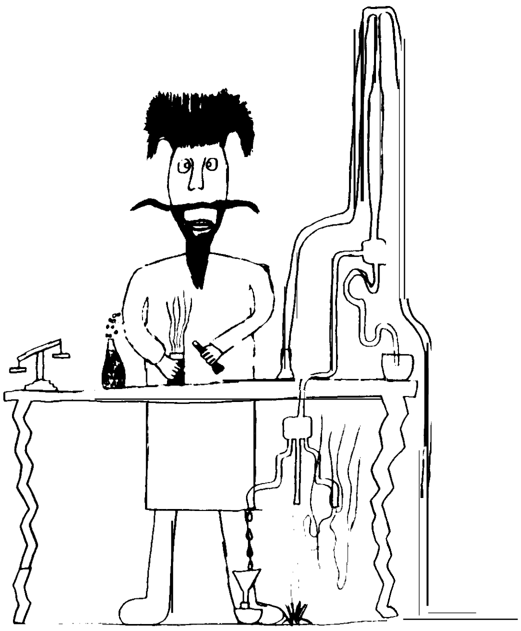
Specific collaborative activities for mathematics teachers include industrial internships, exchange programs with colleges and industries, evening symposia, newsletters, and summer workshops. By fostering collegiality among mathematics teachers and increasing the human and financial resources available to teachers, the projects seek to reduce teachers' isolation and to boost their professional enthusiasm. To further the professional goals of the collaborative, the Foundation has established a Technical Assistance Project that serves as an information clearinghouse on mathematics education and facilitates network communication. The Foundation also funds evaluation of the project through the Wisconsin Center for Educational Research.

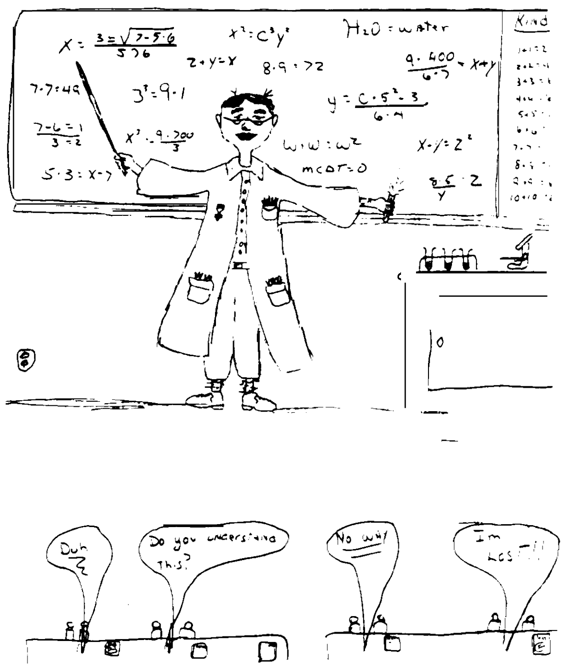
both NSF and the Department of Education, has also funded research on mathematics and science education, as well as data collection. These activities have been very valuable in giving the Nation a picture of what is happening today and how things might be improved.

Future Federal efforts to support science and engineering education can leverage Federal finds if they stress partnerships with programs funded by States, school districts, private industry, and business. An advantage of this approach, other than reducing Federal outlays, is that the burden of evaluating program outcomes is shared by all participants. When this cannot be worked out, however, Federal funds may be the only mechanism for improving the quality of mathematics and science education.

In summary, ways to ensure adequate production of scientists and engineers fall into two distinct groups. One is to enlarge the talent pool, the other is to retain those already in it. Both cast schools as the agent for recognizing and nurturing talent. To assist in these tasks, the system of schooling must become more sensitive to learning styles and varying rates and patterns of children's intellectual development,[43] and more open to community-based programs and institutions. As a Nation, we can explore ways by which science and engineering could more freely welcome those who come to the professions by nontraditional paths.

[41]There is pressure *for redirecting American education to focus 'ore clearly on developing "higher order thinking skills." See Lauren B. Resnick, Education and L-earning to Think (Washington, DC: National Academy Press, 1987). In science, the focus is on investigative and interpretive skills as well as on factual recall, See Robert E. Yager, "Assess All Five Domains of Science," The Science Teacher, vol. 54, No. 7, October 1987, pp. 33-37. There are also suggestions that teaching should be better tailored to suit the way women and minorities learn. Christine 1. Bennett, Comprehensive Multicultural Education: Theory and Practice (Boston, MA: Allyn & Bacon, 1986), ch. 4 and 5; Mark A. Uhlig, "Learning Styles of Minorities to Be Studied," New York Times, Nov. 21, 1987, p. A29; Eleanor Wilson Orr, Twice As Less: Black English and the Performance of Black Students in Mathematics and Science (New York, NY: W.W. Norton & Co., 1987).*






Drawings by elementary school children in response to the question "What does a scientist look like?" (1988).