Chapter 2

Formal Mathematics and Science Education

Photo credit: Neldine Nichols, Wisconsin Department of Public Instruction

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Chapter 2

Formal Mathematics and Science Education

There has been widespread concern among scientists and educators alike over the failure of the instructional programs in the primary and secondary schools to arouse greater interest and understanding of the scientific disciplines. . . . There is general agreement that much of the science taught in schools today does not reflect the current state of knowledge nor does it represent the best possible choice of material for instructional purposes.

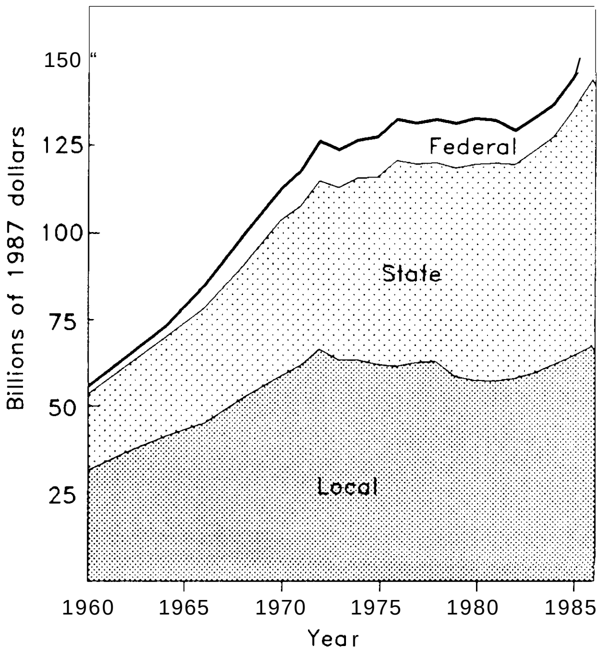
Hearings before the Committee on Appropriations, U.S. Senate, ***1958***

For most people, science education begins and ends in school mathematics and science classes. Science and mathematics education, however, cannot be analyzed in isolation from the overall national system of K-12 education, The national pattern of schooling mixes diversity of control and decisionmaking with a surprising uniformity of organization and goals.

THE NATION'S SCHOOLS

About 75 percent of each birth cohort now graduates from high school. Elementary and secondary education takes place in over 100,000 schools, employing ***2.5*** million teachers and enrolling about 45 million students. [1]It costs $170 billion per year, about $4,000 per student—or 4 percent of the annual gross national product.' Public education, including higher education, is the single largest component of State spending. Nationally, the States' contribution to the cost of public school education is about 49 percent of the total; 45 percent comes from local sources and the remaining 6 percent from the Federal Government. The Federal Government's contribution peaked at about 10 percent of the total from 1978 to 1980.[3] (See figure 2-l.) The balance among local, State, and Federal funding varies significantly from State to State, however. New Hampshire has the highest proportion of local funding, at 90 percent; Hawaii has the highest proportion of State

Figure 2-1 .—Funding of Elementary and Secondary Education, by Source, 1980-87 (constant 1987 dollars)



SOURCE: U.S Department of Education, National Center for Education Statistics, *Digest of* Education *Statistics 1987* (Washington, DC: 1987), p. 107; and unpublished data

[1]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), tables 3, 4, 5, 59. Data on the number of public schools is from 1983-84, that on private schools from 1980-81. The number of school districts is from 1983-84. Student enrollment data is an estimate for fall 1986, number of teachers are estimated full-time equivalent excluding support staff for fall 1986.

[2]Ibid., table 21. Data are estimates for 1986-87.

'Ibid., table 93 (preliminary data for 1984-85).

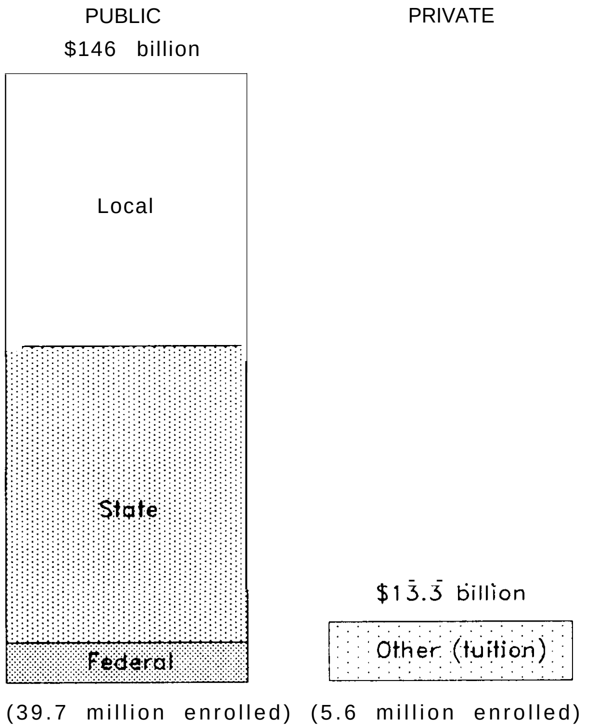
funding, at 89 percent; and Mississippi has the highest proportion of Federal funding, at 16.5 percent.[4]The bulk of the cost of education is in providing buildings and paying salaries for teachers and other staff. A tiny proportion is spent on instructional materials, such as textbooks and laboratory equipment.’ Private schools are funded from tuition charged to students, although they also receive tax benefits and participate in some Federal aid programs. They enroll about 10 percent of students.’ (See figure 2-2.)

[4]Hawaii is the only State to have only one school district. That is, the public schools are, in effect, State run rather than school board run.

‘For example, over one-half of public expenditures on elementary and secondary schools in 1979-80 went to “instruction, ” primarily teacher salaries. U.S. Department of Education, op. cit., footnote 1, table 96. According to data from the American Association of Publishers, the average school district spent $34 on instructional materials per pupil in 1986, of a total spending of $4,000 per pupil, just under 1 percent. Also see Harriet Tyson-Bernstein, testimony before the House Subcommittee on Science, Research, and Technology of the Committee on Science, Space, and Technology, Mar. 22, 1988.

[6]The system of public schools is paralleled by an extensive system of private education for which parents pay tuition (in addition to the taxes that support public schools). The majority of private schools are of religious foundation.

Figure 2-2.— Public and Private School Enrollments and Revenues, by Source, 1985-86



SOURCE: U.S. Department of Education, National Center for Education Statistics

Although control over public education is in the hands of the States and the school districts, schooling across the Nation displays remarkable uniformity.[7] Compulsory education generally begins at age 6, in grade 1; for those who persist, free public schooling ends in grade 12 at age 18. There are three commonly used school classifications: elementary (kindergarten to grade 5, 6, or 7); middle or junior high (grade 6, 7, or 8 to grade 8 or 9); and high (grades 9 or 10 to 12). Schools award grades on a scale that normally stretches from 1 to 4, curricula and course titles are fairly uniform, and a student’s grade point average is nationally recognized as a measure of the student’s progress.

The Nation’s ***84,300*** public schools are controlled and run by autonomous school districts, subject to State laws and systems of organization. These school districts are of very unequal size: the largest 1 percent educate 26 percent of students, while the smallest 43 percent educate only 4 percent of students. The trend is toward consolidation of smaller districts, and the number of school districts has fallen in so years from 120,000 to slightly less than 16,000 today.[8]Most school districts, although geographically coextensive with local governmental units such as counties and cities, raise their own funds through local taxes and bond issues, and are run by locally elected school boards. In other districts, funding and control are the responsibilities of counties and cities.

Just as education nationally displays diversity ***and*** uniformity, so it is with mathematics and science education. The National Science Teachers Association estimates that at least 50 percent (8.3

[7]See, for example, Barbara Benham Tye, “The Deep Structure of Schooling, ” *Phi Delta Kappan*, December 1987, pp. 281-284.

[8]U.S. Department of Education, op. cit., footnote 1, tables 5, 59, 60, 62. Data on the distribution of students among school districts are from fall 1983. Data on the number of public schools are for 1983-84. An often overlooked element of local control in education is the composition of school boards. Ninety-five percent of the 97,000 school board members in the United States are elected. They make policy on everything from school lunch menus to textbook adoption affecting 40 million students. Jeremiah Floyd, National School Boards Association, remarks at Workshop on Strengthening and Enlarging the Pool of Minority High School Graduates Prepared for Science and Engineering Career Options, Congressional Black Caucus Braintrust on Science and Technology, Washington, DC, Sept. 16, 1988.

million) of the high school population enrolled in a science class in 1986.[9] In 1981-82, 78 percent of high school students (9.9 million) were enrolled in mathematics courses. *O To provide these courses in 1985-86 required a work force of about 100,000 science teachers and 173,000 mathematics teachers, who together made up about 30 percent of the secondary school teaching force .11

[9]National Science Teachers Association, ***Survey Analysis of U.S. Public and Private High Schools: 1985-86*** (Washington, DC: March 1987), p. 5. A 1981-82 analysis indicated about the same number of enrollments in high school science courses, 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), p. 17.

[10]Evaluation Technologies, Inc., op. cit., footnote 9, p. 16.

‘lNational Science Teachers Association, op. cit., footnote 9, p. 2; National Education Association, ***Status of the American Public School Teacher, 1985-86*** (West Haven, CT: 1987), p. 11, table 17. (The National Education Association estimates that 11 percent and 4.5 percent of elementary school teachers that specialize in a subject area teach mathematics and science, respectively.)

COMPONENTS OF MATHEMATICS AND SCIENCE CURRICULA

For many children, the content of mathematics and science classes and the way these subjects are taught critically affect their interest and later participation in science and engineering. The effectiveness of different teaching techniques is addressed in the next chapter, but this section reviews the controversies over the typical American mathematics and science curriculum, the alleged dullness of many science textbooks, and the extent to which greater use of educational technology, such as computers, could improve the teaching of mathematics and science .12

Many mathematics and science educators are critical of the quality of the mathematics and science curricula in use in most schools. They see the curricula as slow-moving, as failing to draw links between scientific and mathematical knowledge and real-world problems, and as relatively impervious to reform .13

Typical Mathematics and Science Curricula

The mathematics and science curricula in use in schools are fairly standardized, due to the widespread use of the Scholastic Aptitude Test and American College Testing program for college admissions, college admission requirements, the workings of the school textbook market (which ensures considerable uniformity of content), and the need to accommodate students who transfer from one school to another. Nevertheless, there are important differences in the problems of curricula between mathematics and science .14

In mathematics, grades one to seven are devoted to learning and practicing routine arithmetical exercises. In grade seven, the more advanced students may move on to take courses that prepare them for algebra, but the most commonly offered class is “general mathematics. ” The most able and motivated take algebra in grade eight (if their school offers it), and there is some evidence that the number of algebra classes in grades seven to nine is rising.[15] In higher grades, students go on to courses in advanced algebra (also known as algebra II), geometry, trigonometry, and either precalculus or calculus (where these are offered). (See figure 2-3.) About 10 percent of each cohort

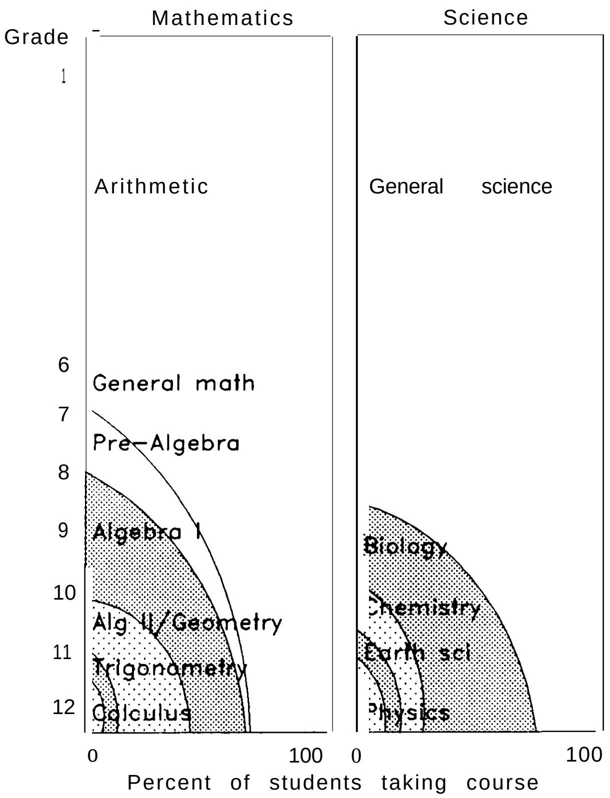
[12]Similar criticisms are made of the entire K-12 curriculum that, according to many observers, fails to draw links between separate courses or between its content and the workings of the outside world. A recent Carnegie Foundation report called for “. . . a kind of peacetime Manhattan Project on the school curriculum. . . .“ which would “ . . . design, for optional State use, courses in language, history, science and the like and . . . propose ways to link school content to the realities of life. ” The Carnegie Foundation for the Advancement of Teaching, ***Report Card on School Reform: The Teachers Speak*** (Washington, DC: 1988), p. 3. See also Fred M. Newman, “Can Depth Replace Coverage in the High School Curriculum,” ***Phi Delta Kappan,*** January 1988, p. 345.

[13]Attempts were made to improve mathematics and science curricula in the 1960s via several projects funded by the National Science Foundation. These projects did have some success, and have affected overall curricula in these subjects in particular by stressing the use of practical experiments. Details on these federally funded programs appear in ch. ***6.***

[14]See, on science curricula generally, Audrey B. Champagne and Leslie E. Hornig (eds.), ***The*** Science *Curriculum:* ***The Report of the 1986 National Forum for School Science*** (Washington, DC: American Association for the Advancement of Science, 1987).

[15]Iris R. Weiss, ***Report of the*** *1985-86 National* ***Survey of Science and Mathematics Education*** (Research Triangle Park, NC: Research Triangle Institute, November 1987), pp. 24-25.

Figure 2.3.—Typical Course Progression in Mathematics and Science



SOURCE: Office of Technology Assessment, 1988.

of high school graduates persist in mathematics long enough to take a calculus course.

The abstract and undemanding pace of the mathematics curriculum at all levels has been widely criticized recently. Many mathematics educators believe that there is too much emphasis on arithmetical drill and practice, as opposed to an emphasis on understanding mathematical concepts and applications. Many highly able students in mathematics, likely future science and engineering majors, report that the average curriculum proceeds at too slow a pace.[16] The fact that handheld calculators—in widespread use in everyday life nationwide for over a decade—are still rarely found or used in mathematics (and science) classrooms is particularly criticized. A 1985 survey found that about one-half of mathematics and science classes in grades 10-12 used calculators at some point, but the proportion was much lower in earlier grades (14 percent in the case of grade K-6 mathematics classes). ” Another survey found that almost all students reported that either they or their family owned a calculator, but less than one-quarter said that their schools had calculators for use in mathematics classes.[18]

Many mathematics educators also note that the mathematics curriculum was largely left out of earlier reform efforts, which concentrated mainly on science. The experiments in “new math” left a bad taste in many mouths, and there still remains deep suspicion among teachers, parents, and school boards of attempts to develop a “new” mathematics curriculum. Nevertheless, mathematics educators are using international comparisons of curricula, teaching practices, and achievement test scores to demonstrate the inferiority of many American mathematics curricula.[19] The National Council of Teachers of Mathematics is undertaking a consultation program to develop curriculum and assessment standards for school mathematics, and the Mathematical Sciences Education Board, part of the National Research Council, is launching a broad-based reform program designed, in part, to alert parents, school boards, and teachers of the need to improve school mathematics. (See box 2-A.) Particular efforts are also being made to improve the teaching of calculus—increasingly taught in high school and, by many accounts, appallingly taught at the college level.’”

[16] Benjamin S. Bloom (cd.), ***Developing Talent in Young People*** (New York, NY: Ballantine, 1985), pp. 303-311; Lynn Arthur Steen, “Mathematics Education: A Predictor of Scientific Competitiveness, ” ***Science,*** vol. 237, July 17, 1987, pp. 251, 252, 302.

[17] Weiss, op. cit., footnote 15, tables 24 and 31, pp. 48, 56.

[18] John A. Dossey et al., ***The Mathematics Report Card: Are We Measuring Up? Trends and Achievement Based on the 1986 National Assessment*** (Princeton, NJ: Educational Testing Service, June 1988), p. 79.

“Curtis C. McKnight et al., ***The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective*** (Champaign, IL: Stipes Publishing Co., January 1987); and Robert Rothman, “In ‘Bold Stroke, ’ Chicago to Issue Calculators to All 4th-8th Graders, ” ***Education Week***, Oct. 14, 1987.

‘“National Council of Teachers of Mathematics, “Curriculum and Evaluation Standards for School Mathematics: Working Draft,” unpublished manuscript, October 1987; Robert Rothman, “Math Group Sets New ‘Vision’ for Curriculum, ” ***Education Week, Nov.*** 11, 1987, p. 5; and Lynn Arthur Steen (cd.), ***Calculus for a New Century; A Pump, Not a Filter*** (Washington, DC: Mathematical Association of America, 1988).

Box 2-A.-The Special Role of the Science and Engineering Research Communities in Mathematics, " and Science ~& , -

Science is an acti laboratories and research facilities all over the world, scientists, engineers, and technicians form communities. These communities provide the colleagues, verification, peer review, and legitimacy of the research enterprise. Members of these communities also prepare future generations of researchers. Many members of research communities have an active interest in science education, even at the precollege level, for they with communicating the joy and beauty of science and with nurturing future waves oft&k Yet, despite the obvious potential linkages between mathematics and science education and the practice of science and engineering, there is still a continuing need to forge those linkages.

Teachers and educators often lament that communities are not actively helping them and remain indifferent to the early preparation of future talent. To an extent, there will always be friction between these groups; many scientists disdain educators, whom they see as merely mass-produced and disseminating yesterday's knowledge, Deep understanding are needed.

Two major initiatives are under way to bridge and enhance education: the American Association for the Advancementt of Science's Project 2061 and the Mathematical Sciences Education Board, based at the National Research Council. Project 2061 together a group of prominent scientists to reform science and mathematics education for the next%! years—vComet alley will next return to Earth. The Project has three phases identification, educational formulation, and educational transformation. In the first phase, the group is attempting '@<d&i& the science, technology, and mathematics that all high school graduates should know. In the second phase, these "goals for learning" will transmute into educational guidelines for curricula, school organization, teacher training and support, and testing methods. Finally, in the third phase:

> . . . the strategies and mechanisms needed to reform American in the light of the intellectual framework of Phase I and the educational guidelines of P&M II will be established and monitored. This phase will have to be a highly cooperative, nationwide effort which will mobilize resources, monitor progress, and, in general, provide direction and continuity of effort.[1]

The Mathematical Sciences Education Board was established in October 1985 with the aim of launching a major reform effort for elementary, secondary, and undergraduate teaching of mathematics, focusing in particular on curricula. The primary purpose of the Board is ". . . to provide a continuing national overview and assessment capability for mathematics education." The Board works under the auspices of the National Research Council, and on it sit mathematicians, mathematics educators, and people familiar with schools and school systems. The Board is working on public understanding of school mathematics issues, raising national expectations for mathematics teaching and learning, and reaching a consensus on goals and education for future mat; planning ways to help States and school districts improve their performance in mathematics.[2]

[1] F. James Rutherford et al., "Project 2061: Education for a Changing Future," *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, 19S7), pp. 61-65.

[2] Lynn Arthur Steen (ed.), Calculus for a New Century: A Pump, Not a Filter DC: Mathematical Association of America, 19SS).

In science, until grade eight, most students take general science courses. In grade nine, upon transfer to high school, they typically take general science, biology, then chemistry, earth science, and finally physics. About *20* percent of high school graduates persist in science long enough to take physics .2] In many schools, these courses are taught separately, and teachers fail to draw the links and contrasts among the different science disciplines. The typical order of their presentation—biology, chemistry, physics—is deeply ingrained in the culture of American school science, but some teachers feel that other arrangements would be better, and would draw more effective links

'*In 1987, 20.1 percent of high school graduates earned minimal credits in physics, up from 13.9 percent in 1982. Westat, "1987 High School Transcript Study, " unpublished tabulations for the "Nation at Risk Update Study, " May 1988, p. 110.

with mathematics courses. (For comparison, see figure 2-4, which outlines the order of courses followed by a science magnet school in which this traditional order is reversed.

Problems With Textbooks

Most mathematics and science in schools is taught with the aid of textbooks, which are an area of considerable controversy (more so in science than in mathematics).[22] Many scientists and science educators are deeply critical of typical science textbooks, which they say concentrate largely on defining terms without explaining their origin and the scientific concepts that they describe. Science, they say, ends up being presented

[22] A 1985-86 survey of teachers indicated that over 90 percent of mathematics and science classes in grades seven to nine used a published textbook or program, a proportion which has remained level since 1977. About two-thirds of elementary science classes use them, as do over 90 percent of elementary mathematics classes. The survey also found that most teachers claimed to cover at least 75 percent of the book that they used. See Weiss, op. cit., footnote 15, tables 14 and 19. A similar survey of students found that three-quarters of students in grade 7 and 11 reported using mathematics textbooks in classes daily, and only 4 or 5 percent, respectively, "never" used textbooks in class. In grade three classes, more use is made of workbooks or ditto sheets than textbooks. See Dossey et a]., op. cit., footnote 18, p. 78.

Figure 2-4.–Curriculum of a Mathematics/Science/Computer Science Magnet Program for the Class of 1991

Year	Mathematics	Science	Seminar	Computer Science
Grade 9	***Course sequence***			
Ist semester	**Magnet Geometry A&B** **(1 credit)** ↓	Advanced Science 1 Physics (1 credit)	Research and Experimentation Techniques for Problem Solving 1 including: Probability and Statistics Research Methods (1/2 Credit)	Fundamentals of Computer Science A **(1/2 Credit)**
2nd semester	Magnet Functions A&B (1 credit) or	Advanced Science 2 Chemistry (1 credit)		Fundamentals of Computer Science B **(1/2 Credit)**
Grade 10				
Ist semester	Magnet Precalculus A,B,C **(1 1/2 Credits)**	Advanced Science 3 Earth Science (1/2 credit)	Research and Experimentation Techniques for Problem Solving 2 (1/2 credit)	Algorithms and Data Structures A (1/2 credit)
2nd semester	Analysis A&B **(1 credit)** ↓	Advanced Science 4 Biology (1 credit)	**(1/2 Credit)**	Algorithms and Data Structures B **(12 Credit)**
Grade 11				
1st semester / 2nd semester	Analysis II (1/2 credit) or Linear Algebra or Discrete Mathematics or Excursion Topics in Math	Advanced mini-courses, research, internships, university courses, special topics, cooperatives, etc. (variable credit)	Research and Experimentation Techniques for Problem Solving 3 (1 credit)	Advanced topics in semester and mini-courses, university study, special topic sessions, projects (variable credit)
Grade 12 Ist semester / 2nd semester	Guided Research, Internship Cooperatives, University courses, etc.	Examples: Climatology, Tectonics, Metallurgy, Cellular physiology, Biomedical seminar, Thermodynamics, Optics, Cooperatives	Guided senior project involving research and/or development across discipline lines (1 credit)	Examples: Analysis of Algorithms, Graphics, Survey of Languages, Computer Architecture & Organization, Game Theory

NOTE: Elective courses for grades 11, 12 include options like: Advanced Placement courses. Game Theory, Topology, Mathematical Programming, Abstract Algebra, Cooperative Languages, Robotics, Computer Architecture, Systems Design, Organic Chemistry, Quantitative analysis, Astrophysics, Plant Physiology, Behavior and Brain Chemistry, Calculus in Biology/Ecology.

SOURCE: Montgomery Blair High School, Silver Spring, MD, September 1987.

as a monolith of unconnected and unchallengeable "facts," which are learned only by those students with extraordinary memories and with an overriding determination to pass the standardized tests of their ability to recall such definitions. (The need to address "facts," as well as their interpretation and construction, is discussed in box 2-B.) As a result, students find the textbooks boring. For example, one recent review by a science educater of a newly revised biology textbook notes:

> [This] product offers facts, pseudofacts and cliches in a matrix of rote sentences and plentiful pictures. It continually fails to integrate information, to explain concepts or to explain biology, and it is rich in absurdity. The writers reduce the topic of "scientific methods" to two paragraphs within a confusing passage on "The Origin of Life." . . . The book . . is attractive but scientifically meaningless.
>
> [The book] presents a frenetic display of facts–a smothering blanket of facts—and it will not inspire scientific thinking in any student or teacher. At most, it will impart an artificial and shallow sense of learning while it damages imagination and creativity .[23]

[23]National Center for Science Education, Inc., *Bookwatch*, vol. 1, No. 1, February 1988,

Box 2-B.—Learning About Science and Processes of Advancing Scientific Knowledge

Science is widely equated by the American public with a huge body of knowledge about physical and human processes that the scientific research enterprise has created. Many teachers similarly equate science with the mass of facts and material found in textbooks. Teachers report that their job is to cover as much of this material as they can and get their students to learn and memorize it. Many teachers say that successive editions of textbooks get bigger and more expensive, as more and more factual material is added. In fact, some teachers are very critical of many textbooks in current use because they feel that they convey a misleading impression of the reality of science and engineering. While scientists share the view that science is a large collection of facts, there are other important dimensions that science students must learn and appreciate to thrive in college-level study.[1]

Science is better viewed as a subject that embraces both a body of knowledge *and* the process by which that knowledge is developed and verified.[2] Future scientists and engineers need to know about what is already known and about how new knowledge can be created.[3] Most scientific knowledge rests on experiments that yield data. These data either confirm or fail to support hypotheses that scientists make about relationships in the physical world. (Rare exceptions are wholly theoretical fields, where physical experiments are intractable and knowledge is built up by theoretical analysis.) Thus knowledge of how experiments are conducted, what sources of error there might be in them, how potentially contradictory evidence is sought and evaluated, and how the results of experiments can be used—both within science and without—is the key to understanding the process of doing science.[4]

A further dimension to the study of science is that of its effects on society and its role in society and government. This dimension is collectively known as "science, technology, and society," and is being introduced into many school science classes.[5]

[1]As the late Roger Nichols, former director of the Boston Museum of Science, said about science: "We take a thing which is essentially a process and convert it into a reading exercise. It's no wonder that the overwhelming majority of children are turned off from science by the eighth grade." Gordon L. Nelson, "Playing 'Basketball' in the Smithsonian," *Chemical & Engineering News*, vol. 66, No. 18, May 2, 1988, p. 38.

[2]Historians and philosophers of science, increasingly in the company of scientists and sociologists of science, have generated a sizable literature in the last quarter-century on science as a *social* process replete with the drama of human emotions—competing egos, frustrating errors, and prizes won and lost. See, for example, Stephen Toulmin, "From Form to Function: Philosophy and History of Science in the 1950s and Now," *Daedalus*, vol. 106, summer 1977, pp. 143-162; Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts* (Beverly Hills, CA: Sage Publications, 1979); and Karin Knorr-Cetina and Michael Mulkay, *Science Observed: Perspectives on the Social Study of Science* (London, England: Sage Publications, 1983).

[3]Mary Budd Rowe, "Science Education: A Framework for Decision-Makers," *Daedalus*, spring 1983, pp. 122-142. Related concerns about the competing pulls of depth v. breadth in the curriculum occur in other subjects. See Fred M. Newmann, "Can Depth Replace Coverage in the High School Curriculum?" *Phi Delta Kappan*, vol. 69, January 1988, pp. 345-348; and Robert E. Yager, "What's Wrong With School Science?" *Science Teacher*, January 1986, pp. 145-147.

[4]Educational Technology Center, *Making Sense of the Future* (Cambridge, MA: Harvard Graduate School of Education, January 1988).

[5]Newsletters that unite and inform elementary and secondary teachers of science, technology, and society include the *SSTS Reporter* (Science Through Science, Technology and Society) edited at Pennsylvania State University, the *Teachers Clearinghouse for Science and Society Education Newsletter* (sponsored by the Association of Teachers in Independent Schools, New York City), and the *Hawkhill Science Newsletter* (for Scientific Literacy), produced by Hawkhill Associates, Inc., Madison, WI.

The evidence is that both the economics of textbook publication and the politics of textbook selection result in "watered-down," poorly written, but attractive and fact-filled textbooks.[24] Some educators bitterly criticize the process of textbook "adoption" (approved for use statewide) used in 22 States. These States have a great deal of control over the content of the books. As a result, textbooks are designed to meet adoption criteria in the few key States such as Texas and California (in kindergarten to grade eight only) that guarantee the largest market if the book is approved. States that do not have textbook adoption mechanisms consequently have a more limited choice of textbooks, because publishers are reluctant to incur the cost of producing new volumes for these smaller markets.

Because of the pressure to include material that will satisfy textbook adoption committees and in order to outdo rival publishers, textbooks typically are large and heavy, profusely illustrated, are often printed in full color, but are surprisingly uniform in content. The books typically increase in size and weight with each edition, becoming more expensive, harder to carry, and more difficult for students to take home and study. The textbooks often include a huge quantity of material, in order to ensure that each State's recommended science curriculum is covered and that all interest groups are mollified. However, many important but controversial aspects of science, most notoriously the theory of evolution, may be omitted or given inadequate treatment.

[24]For criticism of the general textbook situation and suggestions for policy reform, see Harriet Tyson-Bernstein, ***A Conspiracy of Good Intentions: America's Textbook Fiasco*** (Washington, DC: The Council for Basic Education, 1988). Also see Tyson-Bernstein, op. cit., footnote 5; and Richard P. Feynman, ***Surely You're Joking, Mr. Feynman: Adventures of a Curious Character*** (New York, NY: Bantam Books, 1986), pp. 262-276.

Photo credit: William Mills, Montgomery County Public Schools

Formal education relies heavily on textbooks marketed by major publishing companies. Most educators find that these textbooks vary greatly in quality.

Interest groups lobby State textbook adoption committees to ensure that their own viewpoint is included, but the effect is that new text and pictures are added—material is rarely deleted. Ultimately, depth is sacrificed for breadth. And, because the adoption process typically involves an expert panel that quickly skims each volume, the textbooks often are designed to have key words in prominent places and be attractively packaged. The result is often textbooks that are a "lowest common denominator" of inoffensive facts, limited in conveying to students the process of constructing new scientific knowledge or the uses that are made of it. Some have described science textbooks as "glossaries masquerading as textbooks." Often, the "facts" themselves are old or entirely discredited. As a recent analysis of the process of textbook adoption notes:

> We have dozens of powerful ministries of education [States] issuing undisciplined lists of particulars that publishers must include in the textbooks. Since publishers must sell in as many jurisdictions as possible in order to turn a profit, their books must incorporate this melange of test-oriented trivia, pedagogical faddism and inconsistent social messages. . . . Under current selection procedures, those responsible for choosing the best among available books seem blind to the incoherence and unreadability of the book because they are merely ascertaining the ***presence*** of the required material, not its depth or clarity.[25]

In economic terms, the textbook market is quite concentrated, as indicated in table 2-1. For example, almost half of all elementary mathematics classes and 37 percent of all elementary science classes use one of the three most commonly used textbooks in these grades. Only a few textbook publishers supply much of the market. Yet a number of smaller publishers happily coexist along side

[25]Tyson-Bernstein, ***A Conspiracy of Good Intentions,*** op. cit., footnote 24, pp. 7, 109-110; also see National Science Board, ***Science & Engineering Indicators, 1987*** (Washington, DC: U.S. Government Printing Office, 1987), pp. 35-36.

Table 2-1.—Most Commonly Used Mathematics and Science Textbooks

Publisher	Title	Percentage of classes that use book
Science, grades K-6:		
Silver Burdett	*Science: Understanding Your Environment*	17
Merrill	*Accent on Science*	10
D.C. Heath	*Science*	10
Science, grades 7-9:		
Merrill	*Focus on Life Science*	9
Merrill	*Principles of Science*	8
Merrill	*Focus on Physical Science*	8
Science, grades 10-12:		
Holt, Rinehart, Winston.	*Modern Biology*	14
Holt, Rinehart, Winston.	*Modern Chemistry*	9
Merrill	*Chemistry: A Modern Course*	5
Mathematics, grades K.6:		
Addison-Wesley	*Mathematics in Our World*	16
D.C. Heath	*Mathematics*	15
Scott, Foresman	*Invitation to Mathematics*	7
Mathematics, grades 7-9:		
Houghton Mifflin	*Algebra: Structure and Method*	7
D.C. Heath	*Mathematics*	4
Scott, Foresman	*Mathematics Around Us*	4
Mathematics, grades 10-12:		
Houghton Mifflin	*Algebra: Structure and Method*	14
Houghton Mifflin	*Geometry*	8
Holt, Rinehart, Winston.	*Algebra With Trigonometry*	2

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 C.1 and C.2.

the major publishers, supplying either materials for parts of courses or entire texts." Nevertheless, it is not a huge market since it is estimated that, in 1986, the total sales of instructional materials was equivalent to about $34 per student (only about 1 percent of the annual cost of education per student).[27]

Despite these gloomy assessments, a recent survey of mathematics and science teachers found that only a minority of them were concerned about textbook quality. When asked whether the poor quality of textbooks was a serious problem in their school, 11 percent of K-6 science teachers and 5 percent of grade 10-12 science teachers said yes. Fewer than 8 percent of mathematics teachers thought it was a problem. Between 15 and 25 percent of teachers thought that the quality of textbooks was somewhat of a problem. Factors such as large class sizes, inadequate access to computers, lack of funds for equipment and supplies, inadequate facilities, poor student reading abilities, and students' lack of interest were cited to be more serious problems. Indeed, teachers rated the organization, clarity, and reading level of textbooks favorably. Elementary teachers had more favorable ratings of textbooks than did secondary teachers.[28]

Textbooks pose several contradictions: most teachers seem (rightly or wrongly) to like the textbooks they use, many outside reviewers are skeptical of the scientific worth of many mathematics and science textbooks, there are apparently no overwhelming barriers to entry to the market, and powerful political and economic forces shape the dynamics of the textbook market. Devising "better" textbooks is not enough, for they must be adopted to be used and they are likely, on present

[26]A 1985-86 survey found that 10 publishers (Addison-Wesley; Harcourt Brace Jovanovich; D.C. Heath; Holt, Rinehart, Winston; Houghton Mifflin; Laidlaw; MacMillan; Merrill; Scott, Foresman; and Silver Burdett) accounted for at least three-quarters of all mathematics and science textbooks at all levels, and that two publishers accounted for almost one-half of each of elementary mathematics and science textbooks. See Weiss, op. cit., footnote 15, pp. 32-37.

[27]Tyson-Bernstein, op. cit., footnote 5, p. 13 and table II. Based on data from the Association of American Publishers, 1986.

[28]Weiss, op. cit., footnote 15, pp. 40-42 and tables 20, 21, and 71.

evidence, to be severely corrupted in the process. The best teachers have the ability to go beyond the material in textbooks, to provide supplementary material and examples, and to weave the concepts that the books try to explain into some coherent whole. But many teachers do not have the time, energy, or authority to use materials other than the approved texts.

Overall, the deficiencies, if any, in current mathematics and science textbooks stem from the divorce between the buyers and users of textbooks. Greater teacher involvement in textbook selection, a more courageous selection of members of textbook selection committees by States, and a greater participation by qualified scientists and engineers in the textbook adoption process will help, but not rectify, the problem.[29]

Use of Computers in Mathematics and Science Education

Computers offer new approaches for learning mathematics and science for all children, and help prepare students for college courses and technical careers that will demand familiarity with the technology.[30] If used well and imaginatively, computers can increase students' interest and improve learning, particularly for both the most and least advanced students. But the educational impact of computers is limited when the rest of the classroom environment stays the same. Conclusive research on effectiveness is meager.[31]

Computer technology and software are evolving. Educators are still discovering both positive and negative impacts on students, classrooms, and learning; how best to use the technologies to improve learning; and what support is needed in teacher training, curriculum modification, and research. Use of computers by teachers and students is still quite limited, although their availability and the equality of access enjoyed by different schools and students is improving. The use and future impact of computers depends on familiar features of the rest of the school system: curricula, time, quality of overall science and mathematics instruction, and, most of all, the comfort and competence of teachers with computers.

Nature and Extent of Use

The potential of computers is slowly being realized. Regular computer use is not extensive, although almost all schools now have at least some computers available. Primarily because of the small number of computers relative to students (the computer-to-student ratio in science classes is estimated to be 1:15 in middle school and ranging from 1:10 to 1:17 in high school, which is higher than the average in all subject areas), computers are most commonly used as infrequent enrichments rather than as an integral part of science teaching.[32] About one-third of high school mathematics teachers use computers in the classroom.[33] Nevertheless, much of this is occasional

[29] There is a Federal role, too. The National Science Foundation has issued a "publisher initiative" that outlines criteria for needed student assessment materials in baseline science development projects for the elementary grades and middle school. Since 1987, the National Science Foundation has funded seven "Troika" programs ". . . intended to encourage partnerships among publishers, school systems, and scientists/science educators for the purpose of developing and disseminating a number of competitive, high quality, alternative science programs for use in typical American elementary schools." See the National Science Foundation, Science and Engineering Education Directorate, Instructional Materials Development Program, "Publisher Initiative" and "The 'Troika' Program," unpublished documents, July **1988.**

[30] This discussion centers on the now-familiar desktop personal computer or computer with keyboard and/or mouse input. Some schools have networked computers, or links with computers at other sites. Some schools, in particular science-intensive schools, have more powerful computers, computerized laboratory instrumentation, and computer-aided data processing equipment. Other information technologies, such as interactive videodiscs, are also powerful learning tools but they are less widespread than computers. Calculators, present in increasing numbers of classrooms, are having a greater effect than computers, because they reach many more students and are more readily linked in teachers' minds with existing curricula items, such as arithmetic. For more detail, see U.S. Congress, Office of Technology Assessment, ***Power On! New Tools for Teaching and Learning, OTA-SET-379*** (Washington, DC: U.S. Government Printing Office, September 1988).

[31] Henry J. Becker, Center for Research on Elementary and Middle Schools, "The Impact of Computer Use on Children's Learning: What Research Has Shown and What It Has Not," unpublished manuscript, 1988.

[32] Sylvia Shafto and Joanne Capper, "Doing Science Together," ***Teaching, Learning and Technology: A Digest of Research With Practical Implications,*** vol. 1, No. 2, summer 1987, p. 2. A 1985 survey found that over 90 percent of schools had access to computers, but that only in about one-quarter of mathematics and science classes was this equipment readily available. Often, it is shared with other classes, or kept in special-purpose rooms that must be scheduled in advance. Weiss, op. cit., footnote **15,** table 68.

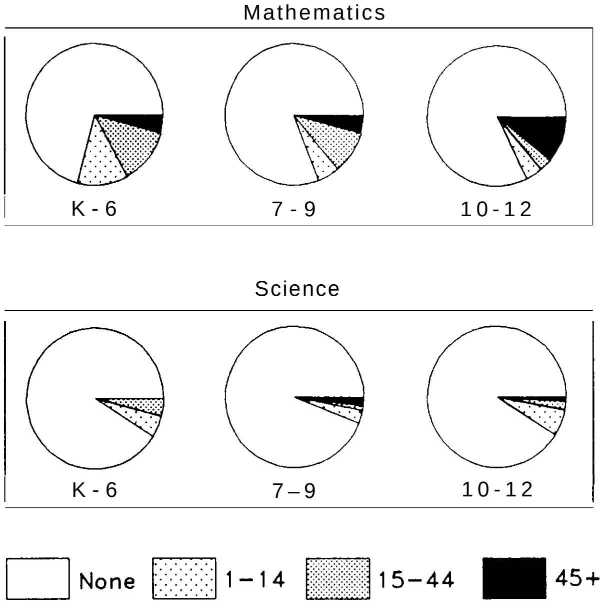
[33] Becker found 17 percent for middle and secondary schools, while the National Science Teachers Association found 26 percent for all schools with a grade 12 (all secondary schools and a few middle schools). See Henry Becker, "1985 National Survey," ***Instructional Uses of School Computers, No. 4,*** June 1987; and National

use, and amounts to a small fraction of instructional time.[34] A 1985 survey noted that ". . . there is only the hint that secondary school science instruction might be profoundly affected by computers. The impact is largely still in the future."[35]

Computers are not used intensively in science classes. (See figure 2-5.) In secondary school, only 5 to 10 percent of computer use is for science; in elementary school, it is about 1 percent. There has been a slight decrease in the number of science programs available over the past 5 years, especially in chemistry and physics.

A unique application of computers in science is in the microcomputer-based laboratory (MBL), where computers can simulate experiments or process and display data obtained from simulated experiments.[36] (See box 2-C.) The use of science laboratories in science teaching has declined for many reasons, but computers can reduce some of the barriers to laboratory work, such as the rising cost of supplies, purchasing and maintaining equipment, concerns about safety hazards and liability, limited teacher competence in experimental work, the complexity of some experimental procedures, and the "one time—look quick" nature of many laboratories.[37] MBLs can also help children learn the process of science and research—hypothesis formation, testing, asking "what if" questions, gathering and analyzing data—at their own pace. Students using MBLs have shown greater understanding of basic principles and skills such as graphing data than students in regular laboratories. w

Figure 2.5.—Time Spent Using Computers in Mathematics and Science Classes, by Grade, in Minutes Per Week, 1985-86



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), p. 59

Besides limited access to machines, other important barriers to more extensive use of computers are teachers' lack of familiarity with the technology and the lack of educational software (computer programs). Surveys indicate that comparatively few mathematics and science teachers have taken courses either in the instructional uses of computers or in computer programming. Only a bare majority of secondary mathematics teachers have taken either of these courses (table 2-2).

About one-half of educational software is devoted to topics in mathematics, science, and computer literacy. Mathematics was one of the first applications of educational computing, and con-

Science Teachers Association, "Survey Analysis of U.S. Public and Private High Schools: 1985-86," unpublished document, March 1987.

[34] A 1985-86 survey found that, in grades 10-12, 10 Percent of mathematics classes and 5 percent of science classes used computers in their last lesson, but one-third of courses of each type used them at some point. Elementary students spend more time with computers than secondary students, but still two-thirds of K-6 mathematics classes and 85 percent of K-6 science classes report not using computers at all "last week." Weiss, op. cit., footnote 15, pp. 48, 58, 59, tables 24, 32, 33. Another recent survey has found computer access for learning mathematics to be relatively equitable across the sexes, races, and ethnicities, although high-ability students are more likely to report that they have access than are low-ability students. About one-third of high school juniors have taken a computer programming course. Dossey et al., op. cit., footnote 18, pp. 82-86.

[35] Becker, op. cit., footnote 33, p. 11.

[36] Shafto and Capper, op. cit., footnote 32, p. 1. However, computers are used much more widely in the science classroom than in the laboratory.

[37] Alan Lesgold, "Computer Resources for Learning, *Peabody Journal of Education, vol. 62, No. 2,1985,* cited in Shafto and Capper, op. cit., footnote 32, p. 4. A 1985 survey found that the number of mathematics and science classes that had used "hands-on" activities in their most recent lesson had declined at all grade levels (with the sole exception in K-3 mathematics) since 1977. For example, while 53 percent of grade 10-12 science classes in 1977 reported using hands-on activities, in 1985 only 39 percent did. Weiss, op. cit., footnote 15, table 25, p. 49.

340 ffice of Technology Assessment, op. cit., footnote 30, ch. 5.

Box 2-C.—National Geographic Society (NGS) Kids Network: Students as Scientists

One great potential of computers is to allow children to do "real science"—to design and conduct experiments, collect data, display the results, try "what if" experiments, compare their results with those of other students, look for unusual results and patterns, and try to understand what it all means. Most school laboratories run "cookbook" experiments with predetermined outcomes. There are various ways computers are used to teach experimentation: to simulate experiments; to provide real-time, visual data analysis of regular "wet" experiments in microcomputer-based laboratories; and, in the NGS Kids Network, to use telecommunications to link children across the Nation in a real experiment.

The NGS Kids Network uses networked computers and telecommunications to link elementary school children around the United States. During a month-long 1987 pilot Kids Network project on acid rain, students in nine States did classroom work, collected rain samples, measured pH, and shared their results over a telecommunications network. A project coordinator analyzed the results and distributed them to all the participating classes. With the reach and immediacy of national data collection and analysis, the students could see their results, and those of all other students, overnight.

The chief impact of the NGS Kids Network, as with much computer use, seems to be in getting children, teachers, and parents excited and involved. Enthusiasm generally improves learning. Formal evaluation of the impact of the Kids Network and computers on understanding science concepts and methods, however, is likely to be less clear-cut.

> Results of the trial far exceeded expectations. The students puzzled over their measurements and wondered why Nebraska had such an unexpectedly high level of acid rain. (In fact, this finding is in accord with recent EPA measurements.) They learned about acids and bases, about dilution, pH scales, the range of accuracy of measuring indicators, the possible effects of acid rain, and latitude and longitude. Students became engrossed in finding out more about the communities where the other sites were located. They learned valuable lessons about the process of science, engaged in spirited discussions about scientific method, the validity of data, and the need for care in measurement. Students were highly motivated, bringing in newspaper clippings, collecting additional samples, and spontaneously writing to students at other sites and to public officials. Uniformly impressed by the unit, teachers enjoyed teaching it.[1]

Future NGS Kids Network units will be self-contained, 1-month packages of classroom activities. "Close to home" topics such as water and air pollution, food growing, solar energy, and weather forecasting have been chosen because they adapt well to distributed, national observations and data collection. One teacher commented:

> After they had brought in their samples of rain water and saw that they had gotten different results, they decided that they hadn't collected enough data. They made a judgement that they didn't have enough data to make an accurate conclusion. I see that as a very important step in understanding science. . . . They got the message that science is a collective enterprise as opposed to an individual one. That message came through very strongly.[2]

Special resource materials, teacher training, and user-friendly software have been developed to make the sophisticated units extremely easy for the novice student and teacher to use. To communicate results, all the teacher or student has to do is switch on the computer. Dissemination will be through the National Science Teachers Association, science centers, and the extensive National Geographic infrastructure.

The Kids Network is being developed by the Technical Education Research Centers and is funded by the National Science Foundation and the National Geographic Society. With the development costs thus supported, the costs to the schools can be kept low; telecommunications costs are a large and uncertain factor. Total development costs, including government and private grants and in-kind equipment and service donations, are estimated at a total of $5 million over 4 years.

[1] Robert Tinker, Technical Education Research Centers, "Network Science Arrives," *Hands On!* vol. 20, No. 1, winter 1987, pp. 1, 10-11.
[2] Ibid.

Table 2-2.—Courses in Computers Taken by Mathematics and Science Teachers

	Percentage of teachers that have taken	
	Instructional uses of computers	Computer programmina
Mathematics teachers:		
Grades K-3	30	17
Grades 4-6	34	24
Grades 7-9	40	46
Grades 10-12	42	64
Science teachers:		
Grades K-3	31	11
Grades 4-6	37	21
Grades 7-9	33	33
Grades 10-12	30	33

SOURCE **Ins R Weiss, Report** *of the 1985-86 National Survey of Science and Mathematics Education* **(Research Triangle Park, NC: Research Triangle Institute, November 1987), tables 39, 40, 41, and 44,**

tinues to be the subject where students are most likely to encounter computers. More software is available for mathematics than for any other subject area, although most of it is for learning and practicing basic skills.” For example, interactive computer graphics can be powerful in helping children construct graphs and visualize algebraic and geometric functions.

Computer Impacts, Opportunities, and Needs

Computers offer the potential for individualized instruction. If carefully developed and used, computers and software can open doors to mathematics and science for students, particularly females and minorities, who traditionally have had limited interest or success in these courses. In many settings, however, computers can also reinforce existing patterns and stereotypes: boys tend to crowd girls away from computers, affluent children benefit from computers at home and more extensive access at school. Little is known as yet of the impact of different kinds and intensity of computer use on interest in, and preparation for, different college majors.

Computers also make it possible to offer courses that might not otherwise be available. Distance learning or packaged computer courses can enrich the schooling of advanced high school students or rural students in schools with limited course offerings. Likewise, familiarity with computers is becoming expected of incoming college students, particularly in science and engineering. If students do not have the opportunity to work with computers, computers may become yet another barrier to attainment of educational goals.

A pressing need is to help current science and mathematics teachers become comfortable using computers in the classroom and laboratory. Although most new teachers being trained are exposed to computers, many of them still report not being comfortable using them.[40] Technology training has unique aspects that distinguish it from other inservice training, in particular a need for special facilities and equipment. Teachers must have generous access to computers to use them effectively.

Continuing research on learning and evaluations of the effectiveness of computer-aided education are needed. Trials of different schools and learning structures would help in evaluating the strengths and weaknesses of computer technologies. The challenge is to measure the process of learning, and not just the content and outcomes of acquired knowledge. Another need is development of computer-integrated curricula, which builds the strengths of computers into curricula from the start rather than appending them to existing curricular frameworks.

The Federal Government has helped schools acquire computers, supported research on their uses and their integration with curricula, and to some extent augmented private sector development of hardware, software, and services .4] Some Department of Education funds, although not specifically targeted to computers, have

[39]Ibid.

[40]Less than one-third of recent graduates fee] prepared to teach with computers. See ibid., p. 98.

[41]Ibid., and Arthur S. Melmed and Robert A. Burnham, “New Information Technology Directions for American Education: Improving Science and Mathematics Educationr ” report to the Nationa] Science Foundation, unpublished manuscript, December 1987.

helped schools acquire hardware and software. Title II of the Education for Economic Security Act of 1984 (see ch. 6) has supported teacher training. The National Science Foundation has been instrumental in software development, networking among schools, and teacher training. Federal influence has been small compared to that from equipment manufacturers or vendors (among whom Apple has been prominent) and private foundations.[42] States are active in the movement to improve basic skills (including mathematics and science literacy), in which computers are playing an increasing role.

'The Federal Government could promote software development. Melmed and Burnham, op. cit., footnote 41, pp. 12-13, suggest that the Federal Government fund four mathematics and four science curricula to meet the goal of a science and mathematics course each year of high school. A rough estimate is that such development would cost about $2 million ($1 to $4 million) per course. Development should include review of old and existing curricula. Distribution and maintenance might total 25 percent of development costs, but could be recovered through a school user fee, Trials would need to be several years long.

VARIATION AMONG SCHOOLS

As any parent knows, schools vary in a myriad of ways; their location, control, and funding may affect their children's progress. For example, there is some evidence that private Catholic schools are especially effective at channeling their students toward academic college education, owing to the personal attention and high expectations they give their students.[43]

OTA did not analyze data on the special features of mathematics and science instruction in private schools compared with public schools. Rather, it considered the contrasts among urban, suburban, and rural public schools, as related to their respective socioeconomic settings and expectations of parents and other taxpayers. For example, urban school districts often have poor tax bases and cannot readily raise funds for education. Suburban school systems have much less difficulty and can attract good teachers. There are continuing pressures for some suburban and urban school systems to merge or to share funds and resources, in the interests of both racial and financial equity. The health of inner city schools will be particularly important in encouraging minority youth to pursue science and engineering majors. The 44 largest urban school systems, represented by the Council of Great City Schools, enroll about 10 percent of the entire school population, but 33 percent of the Blacks and 27 percent of the Hispanics in public schools. These schools also enroll a disproportionately large number of students whose family incomes are below the poverty line.[44] Data from the National Assessment of Educational Progress (NAEP) assessments of science and mathematics achievement indicate that students in disadvantaged urban areas score an average of about 20 percent lower than the national average, while those in suburban areas score about 5 percent higher than the national average.[45]

[43]James S. Coleman and Thomas Hoffer, ***Public and Private High Schools*** (New York, NY: Basic Books, 1987) is a recent analysis of this proposition. Although this analysis does not specifically separate out mathematics and science education, the authors conclude that the ethos of the community surrounding a school, including taxpayers and parents, is more important in explaining the success of private schools than are particular actions that the school takes. Some argue that the political and bureaucratic milieux within which public schools operate harms them. See John E. Chubb and Terry M. Moe, "No School Is an Island: Politics, Markets, and Education, " ***The Brookings Review,*** fall 1986, pp. 21-28. Other analysts have found that any advantage in the outputs of private school science experiences are balanced by the strong self-selectivity of private school students. See John R. Staver and Herbert J. Walberg, "An Analysis of Factors That Affect Public and Private School Science Achievement, " ***Journal of Research in Science Teaching,*** vol. 23, No. 2, 1986, pp. 97-112.

[44]William Snider, "Urban Schools Have Turned Corner But Still Need Help, Report Says, " ***Education Week, vol. 7, No. 2,*** Sept. 16, 1987, pp. 1, 20. Also see Bruce L. Wilson and Thomas B. Corcoran, ***Places Where Children Succeed: A Profile of Outstanding Elementary Schools,*** Report to U.S. Department of Education, Office of Educational Research and Improvement (Philadelphia, PA: Research for Better Schools, December 1987).

[45]U.S. Department of Education, op. cit., footnote 1, table 79. This statement is based on mathematics data for 1981-82 and science data for 1976-77. Due to cutbacks in the Department of Education's funding for the National Assessment of Educational Progress, a limited science assessment was conducted in 1981-82 with funding from the National Science Foundation. Data from that assessment were not tabulated by the geographic location of respondents, so cannot be used in this comparison. The 1986 assessment in mathematics shows continued gains by Black and Hispanic students in all three age categories (9, 13, and 17). See Dossey et al., op. cit., footnote 18.

Rural school systems face different problems in providing high-quality education, particularly in advanced mathematics and science, to geographically dispersed populations. While the days of the one-school school district are passing, rural districts still find it difficult to provide optional advanced mathematics and science courses and to attract the best teachers. These problems will grow worse in areas of rural America that continue to experience economic declines. Experiments are under way in some areas with distance learning technologies and regional science high schools. ”

Standardized Achievement Testing

Students take many kinds of tests throughout their schooling to measure their learning and mastery of skills. Such tests are used to sort students among classes and tracks, to evaluate performance, to check for special abilities (see section in ch. 4 on programs for gifted and talented students) or learning disabilities, and to inform the college admissions process. Tests of basic competencies of high school graduates are growing in favor as part of the movement toward increased educational accountability. A 1985 survey found that 11 States required such tests of high school graduates, and 4 had plans to institute such tests.[47]

Many of these tests are of the familiar standardized multiple-choice type. Scores report students' progress both in absolute terms and relative to the performance of their peers. Such tests are inexpensive to administer; scoring is often done by computer.

But testing is controversial on several counts. It is said to deter many students from preparing for science and engineering careers. The tests are also said to convey racial, cultural, and gender biases against women and ethnic minorities that ostensibly lead to lower scores .48 Some claim that testing has a pervasive harmful effect on the curriculum: teachers invite students to parrot back facts they have memorized, with the result that students' higher order thinking skills are not exercised.[49] A recent issue of the Newsletter of the National Education Association's Mastery in Learning Project put the issue most dramatically:

> Perhaps it has been the failure to understand intelligence —how it is nurtured or stunted, how it works, how it should be measured, even where it resides—that has done the most damage to the education of children.
>
> Because the workings and the vulnerability of the intellect have been so dimly understood by so many, teaching has often been rigidly fact-driven, heavily demanding of linguistic, logical, linear thinking skills, and often neglecting those aspects of learning that involve imagery, intuitiveness, manual and whole body skills, and feelings.
>
> Partly because of this failure of understanding, educational testing companies have continued to produce, states to require, and schools to administer, paper and pencil tests that, in purporting to measure students' achievement, have succeeded only in labeling and limiting it. [w]

The current practice of educational testing appears to constrict the pipeline for future scientists and engineers. It measures only a limited range of abilities and is often misused to deny students access to courses and encouragement that might tip the balance toward their becoming scientists and engineers. Alternative tests are being devised to address, in particular, knowledge of the processes of science, familiarity with experimental techniques, and higher order thinking skills, but the nagging problem will be resistance to their replication and large-scale adoption both for classroom use and in the college admissions process.[51]

[46]E. Robert Stephens, "Rural Problems Jeopardize Reform," *Education Week*, Oct. 7, 1987, pp. 25-26. A new federally sponsored project called ACCESS, in northwest Missouri, is designed to expand rural students' access to higher education in all subjects. Legislation has been introduced to set up similar programs in other States. See Robin Wilson, "U.S.-Backed Project in Missouri Aims to Help Rural Youths Overcome Farm Troubles and Continue Their Education, " *The Chronicle of Higher Education,* Apr. 27, 1988, pp. A37-A38.

[47]U.S. Congress, Office of Technology Assessment, "State Educational Testing Practices, " background paper, NTIS #PB88-155056, December 1987.

[48]Nevertheless, it is important to note that Asian students typically do better than other groups on the mathematics portion of these tests, indicating the difficulty of pinning down exactly what form any racial and cultural biases take.

[49]A comprehensive review is found in Norman Frederiksen, "The Real Test Bias: Influences on Teaching and Learning, " *American Psychologist, vol. 39, No. 3,* March 1984, pp. 193-202.

'National Education Association Mastery in Learning Project, *Doubts and Certainties, vol.* II, No. 6, April 1988, p. 1.

[51]The Assessment of performance Unit of Great Britain's Department of Education and Science, for example, has devised tests of students' skills in conducting experiments and in interpreting these

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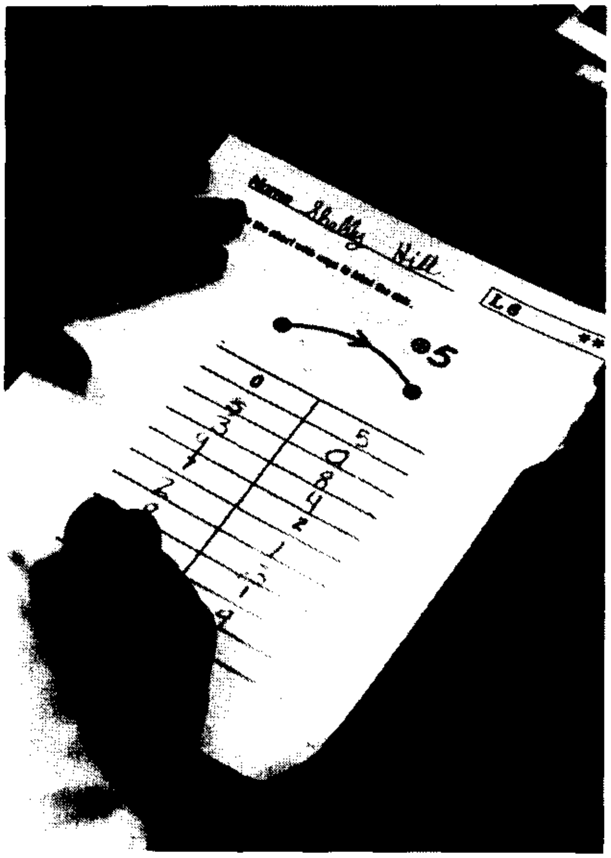

Photo credit: William Mills, Montgomery County Public Schools

Students are tested early and often in schools; this can help in evaluating their learning progress, but it also profoundly affects the curriculum.

The biggest controversies in testing, as it affects those who will major in science and engineering, have concerned the Scholastic Aptitude Test (SAT) and the American College Testing program, one of which almost all intending college students take prior to admission .52 Because these tests are given great weight in admissions decisions by colleges and universities, any deficiencies in the preparation or administration of these tests could lead to "misassignment" of students among colleges and majors, or the failure of students to be admitted to college at all. Standardized tests have been important in college admissions for many decades, because they are economical to administer and measure students nationally against a common metric. But criticism of, in particular, the SAT by activist groups such as the Cambridge-based National Center for Fair and Open Testing (FairTest) and others in education is leading a small but increasing number of colleges and universities to drop their requirement for applicants to take the SAT.[53]

Females, Blacks, and Hispanics, on average, score lower than males and whites on the mathematics and verbal portions of these tests. In relation to disparities on the mathematics portion, some argue that this difference arises from the relatively poor preparation and limited number of mathematics and science courses taken by these groups. But others say that subtle biases in the tests' design and administration are a cause of some of the disparity .54

One important trend in testing is the increasing number of advanced placement programs being offered by schools. These programs give high school students college credit in a particular subject, based on the results of an examination which involves both multiple-choice and written responses. Many argue that this makes the advanced placement a better test, although it is more expensive than regular college admissions tests (costing over $50 per test). The number of such tests being taken is increasing about ***13*** percent annually, and about ***20*** percent of all secondary schools

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results. These tests have been replicated by the National Assessment of Educational Progress and in the advanced placement biology examination. Fran **Blumberg** et al., ***A Pilot Study of Higher-Order Thinking Skills Assessment Techniques in Science and Mathematics*** (Princeton, NJ: National Assessment of Educational Progress, November **1986).** Also see Robert E. **Yager,** "Assess All Five Domains of Science, " ***The Science Teacher,*** October 1987, pp. 33-37; and George E. Hein, "The Right Test for Hands-on Learning, " ***Science and Children,*** October 1987, pp. 8-12.

[52]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. 35-36. Also see Elizabeth Greene, "SAT Scores Fail to Help Admission Officers Make Better Decisions, Analysts Contend, " ***The Chronicle of Higher Education,*** July 27, 1988, p. A20.

[53]David Owen, ***None of the Above*** (Boston, MA: Houghton Mifflin, 1985); Robert Rothman, "Admission Tests Misused, Says College Leader," ***Education Week, Dec.*** 9, 1987, p. 5. **FairTest** reports that at least 40 colleges now do not require either the Scholastic Aptitude Test or the American College Testing program for college admission. When colleges do not use these tests, they increase the weight that they place on other components of the admissions process, such as student transcripts, student essays, teachers' and counselors' recommendations, and in-person interviews. These components arguably allow candidates to present a much fuller impression of themselves as potential college students than do simple scores on standardized tests.

[54]**See National** Science Board, op. cit., foonote 2S, p. 23, which sides with the "poor preparation" hypothesis.

and 10 percent of high school graduates now participate. About one-third of the examinations taken are in mathematics and science.[55]

Patterns of High School Course Offerings and Enrollments

Along with family encouragement and expectations, preparation in high school mathematics and science courses is vital to success in college-level science and engineering studies. Students' exposure to the traditional college-preparatory sequence of mathematics and science courses is restricted by both the course offerings of their schools and their willingness to take those courses. Minorities in particular often have less access to advanced mathematics and science courses, because school districts with high minority enrollments often cannot afford to offer many such courses. Offerings in rural and urban schools are generally more limited than those in suburban schools.

Even when advanced courses are offered, students who could benefit from them often fail to take them. The point at which students are first allowed to decide which mathematics or science courses they are to take is widely believed to be an important fork in the educational pipeline for future scientists and engineers. Once students fail to pursue the normal preparatory sequence of courses, it becomes hard for them to catch up.

Research indicates that there is a positive correlation between the number of advanced high school mathematics and science courses taken and two educational outcomes: achievement test scores and students' intentions to major in science and engineering.[5b] Correlations between mathematics or science course-taking and achievement test scores have been found in analyses of data from both the NAEP mathematics assessment of 1982 (for mathematics courses) and the 1980 High School and Beyond (HS&B) survey of the sophomore cohort (for both mathematics and science courses) .57 These findings were sustained even after statistical allowance was made for student's race, ethnicity, socioeconomic status, and earlier test scores. A strong correlation between high school mathematics course-taking and the major choices of college students was found in an OTA analysis of the ***1980*** HS&B cohort, even when many other factors were statistically controlled .58

Mathematics course-taking, presumably due to its sequential nature, appears to be more important for success in later science and engineering study than science course-taking. The College Board recently noted in *Academic* ***Preparation for Science,*** a handbook that advises high school teachers about what colleges would like them to teach, that knowledge of scientific skills and fundamental concepts will be more important to students than the number of high school science courses they have completed.[59]

It is difficult to be sure that the number of mathematics and science courses taken is a principal influence in the decision to major in science or engineering.[60] However, such courses do keep students in the pipeline,

Course Offerings and Enrollments

Students cannot take courses their schools do not offer. Only a few schools offer the complete

[55]Jay Mathews, "Tests Help 'Ordinary' Schools Leap Ahead, " ***Washington Post,*** May 14, 1987. In 1985-86, 7,201 schools participated out of **30,000** secondary schools nationally. Garfield High School in Los Angeles, featured in the recent movie "Stand and Deliver, " has become one of the top ***10*** schools in the Nation for the number of students who take and pass the advanced placement calculus test. Garfield is located in a poor and predominantly Latino neighborhood.

S"The correlation between outcomes such as these and the number of mathematics courses tends to be stronger than that with the number of science courses.

"Josephine D. Davis, *The Effect of Mathematics Course Enrollment on Racial/Ethnic Differences in Secondary School Mathematics Achievement* (Princeton, NJ: Educational Testing Service, January 1986); and Lyle V. Jones et al., "Mathematics and Science Test Scores as Related to Courses Taken in High School and Other Factors, " ***Journal of Educational Measurement,*** vol. 23, No. 3, fall 1986, pp. 197-208.

"Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition, " OTA contractor report, 1987.

[59]The College Board concludes that the amount of high school science course-taking makes relatively little difference to students' subsequent college performance in science. OTA is skeptical of this conclusion. See below and College Entrance Examination Board, ***Academic Preparation in Science: Teaching for Transition From High School to College (New*** York, NY: 1986), pp. 14-16. See also Robert E. Yager, "What Kind of School Science Leads to College Success?" ***The Science Teacher,*** December 1986, pp. 21-25.

'College Entrance Examination Board, op. cit., footnote 59, pp. 14-16.

range of college-preparatory mathematics and science courses, a deficiency that has persisted for many years.[61] Data on course offerings and enrollments are plagued with inconsistencies. For example, courses with the same titles may have different content while those with near-identical content may have different titles. Inconsistencies in data make the task of comparing schools, States, and years very difficult.

The most recent data on course offerings comes from the ***1985-86*** National Survey of Science and Mathematics Education, sponsored by the National Science Foundation.[62] This survey used the same course classification system as a 1977 survey, permitting comparisons over time. Over 90 percent of high schools offer at least algebra I, algebra II, and geometry, but advanced course offerings are more limited. Only about 31 percent of schools offer a full calculus course (although some senior-year mathematics courses may include an introduction to calculus), and 18 percent offer a course leading to the advanced placement examination in calculus. In science, over 90 percent of high schools offer at least 1 year of biology and chemistry, and 80 percent offer 1 year of physics.

Since 1977, mathematics course offerings have increased somewhat, though the proportion of schools offering calculus has remained constant. Science course offerings have increased slightly. In general, schools offer only one section of these college-preparatory courses. It is not clear whether this outcome restricts or reflects demand for such courses. For example, ***23*** percent of U.S. high schools offer only one section of biology and 52 percent offer only one section of physics.[63]

Data on ***course*** enrollments in mathematics and science indicate that the proportion of high school graduates that have taken college-preparatory mathematics and science courses is very small (again see figure 2-3). While 77 and 61 percent of students took algebra I and geometry, respectively, only 20 percent took trigonometry and only 6 percent took calculus. In science, 90 percent took biology, but only 45 percent took chemistry I and 20 percent took physics. All of these proportions (except for calculus) represent increases from 1984.[64]

Another analysis of the same database, which used a somewhat different course classification, suggests that, even where courses are offered, enrollments are low. About 80 percent of the students to whom the course is available enroll in algebra I, 48 percent in geometry, and about 20 percent in trigonometry. Similarly, in science, while almost all students to whom it was offered took biology, about one-third of the students with the chance to take chemistry did so as did only 10 percent of the students offered physics.[65]

More recent data from the 1985-86 NAEP in mathematics provide a "snapshot" view of enrollments in mathematics classes (see table 2-3, but note that the classification of courses used here differs from that used in other tables). These data suggest that advanced course-taking in mathematics remains at a small proportion of 17-year-olds, although there were some very small increases between 1982 and 1986. Because these data were taken from 17-year-olds, who have the senior year of high school to go before graduation, they do not provide a complete picture of high school course-taking.

These findings send a clear message: offerings of pipeline mathematics and science courses are constrained. More importantly, even when they are offered, only tiny numbers of students take them.

'*Some advanced courses are offered to high school students by community colleges, but there are ***no*** national data on this phenomenon.

[62]Weiss, op. cit., footnote 15. No separate data are available on offerings and enrollments in laboratory courses; data on the amount of time different mathematics and science classes spend on laboratory work is included in ch. 3.

[63]These data are confirmed by a National Science Teachers Association survey. See Bill G. Aldridge, "What's Being Taught and Who's Teaching It," ***This Year in School Science 1986: The Science Curriculum,*** Audrey B. Champagne and Leslie E. Hornig (eds.) (Washington, DC: American Association for the Advancement of Science, 1987), ch. ***12.***

[64]Westat, op. cit., footnote 21. Data from 1982 are presented in the U.S. Department of Education, National Center for Education Statistics, "Science and Mathematics Education in American High Schools: Results From the High School and Beyond Survey, " NCES 84-211b, Bulletin, May 1984, tables A-3, A-4, A-5. In general, Asian students are two to four times as likely to take advanced biology, chemistry, and physics courses than other minority students.

[65]Evaluation Technologies, *Inc.,* op. cit., footnote 9.

Table 2-3.–Trends in Mathematics Course-Taking, 1982-86

	Percentage of 17-year-olds by the highest level of mathematics course they have taken						
Course	Year	Total	Males	Females	Black	Hispanic	White
Pre-algebra	1982	24	25	24	34	37	32
	1986	19	19	19	31	25	17
Algebra I	1982	16	16	17	20	21	15
	1986	18	17	18	18	24	17
Geometry	1982	14	13	15	10	12	15
	1986	17	15	18	16	16	17
Algebra II	1982	39	39	39	29	24	41
	1986	40	39	40	31	28	42
Pre-calculus or calculus	1982	5	6	5	4	3	5
	1986	7	8	5	3	6	7

SOURCE: John A. Dossey et al., *The Mathematics Report Card: Are We Measuring Up? Trends and Achievement Based on the 1986 National Assessment* (Lawrence Township/Princeton, NJ Educational Testing Service, Inc., June 1988), table 8.2,

Females and Minorities Lag in Course-Taking

Females, Blacks, and Hispanics, according to the HS&B survey, fall behind their white male peers in enrollments in high school advanced mathematics and science courses. This finding is **confirmed in data collected for the 1985-86 NAEP mathematics and** science assessments.[66] Tables 2-4 and **2-5** show that, as one follows the normal

[66] For mathematics data, see Dossey et al., op. cit., footnote 18, pp. 116-117. Science data are due to be published in fall **1988.**

Table 2.4.—Percentage of 1982 High School Graduates Who Went on to Next "Pipeline" Mathematics Course After Completing the Previous Course

	Percentage that took geometry after passing algebra	Percentage that took algebra II after passing geometry	Percentage that took trigonometry after passing algebra II	Percentage that took calculus after passing trigonometry
sex:				
Males	67	55	43	31
Females ... ,	63	52	34	30
Of those earning As or Bs on previous course, by sex:				
Males	82	62	55	47
Females	74	61	45	41
Race/ethnicity:				
Hispanics	50	47	28	28
Black	57	55	29	29
White	67	54	40	30
Of those earning As or Bs on previous course, by race/ethnicity:				
Hispanic	64	56	45	48
Black	74	62	48	31
White	79	62	50	43
(Urbanicity of school:				
Urban high school	65	55	36	25
Suburban high school	69	52	40	33
Rural high school	58	55	39	26
Regional differences:				
New England	76	76	32	50
Mid-Atlantic	64	54		40
West North Central	66	45	48	9
West South Central	53	62	32	19
Curricular track:				
General	52	41	27	
Academic	82	61	45	36
Vocational	43	35	19	11

NOTE: The source from which this tabulation is derived does not include the total numbers of students in these samples. Also the data (as originally reported) do not indicate the actual *order* in which the courses were taken, only that the students had taken these courses before graduating from high school. To this extent, the tabulation forces an artificial formalism on the order of course-taking.

SOURCE: C. Dennis Carroll, *Mathematics Course Taking by 1980 High School Sophomores Who Graduated in 1982* (Washington, DC: U.S. Department of Education, National Center for Education Statistics, April 1984),

Table 2.5.-Percentage of 1982 High School Graduates Who Went on to Next "Pipeline" Science Course After Completing the Previous Course

	Percentage that took biology after passing general science	Percentage that took chemistry after passing biology	Percentage that took physics after passing chemistry
Sex:			
Males	72	39	47
Females	75	37	31
Of those earning As or Bs on previous course, by sex:			
Males	79	59	61
Females	79	50	40
Race/ethnic/ty:			
Hispanics	71	21	33
Black	74	28	27
White	74	42	40
Of those earning As or Bs on previous course, by race/ethnicity:			
Hispanic	75	32	43
Black	78	43	41
White	79	57	51
Urbanicity of school			
Urban high school	72	33	39
Suburban high school	73	41	40
Rural high school	75	36	37
Regional differences:			
New England	76	47	**44**
Mid-Atlantic	74	49	**44**
West South Central	83	29	20
Mountain	74	28	35
Curricular track:			
General	71	21	23
Academic	83	59	44
Vocational	64	15	22

NOTE: The source from which this tabulation is derived doesnot include the total numbers of students in these samples. Also the data (as originally reported) do not indicate the actual order in which the courses were taken, only that the students had taken these courses before graduating from high school. To this extent, the tabulation forces an artificial formalism on the order of course-taking.

SOURCE: Jeffrey A. Owings, *Science Course Taking by 1980 High School Sophomores Who Graduated in 1982* (Washington, DC: U.S. Department of Education, National Center for Education Statistics, April 1984).

sequence of mathematics and science courses designed as preparation forcollege-level study inscience and engineering, there is constant attrition in all categories of students. The attrition of females, Blacks, and Hispanics is much greater than that of white males. Black and Hispanic 17-year-olds instead are more likely to report that their highest mathematics course was pre-algebra than white students.

For example, while ***5.6*** percent of all high school graduates in 1982 took calculus, only 2 percent of Blacks and 2.4 percent of Hispanics did. The situation showed little change by 1986, according to NAEP data, although Hispanic students had doubled their participation in pre-calculus or calculus classes in that time. The gender difference, however, is not so pronounced: 5 percent of females and 6.1 percent of males take calculus.

Another way of examining these data is in terms of the proportion of students—by sex, race, and ethnicity—that go on to take a higher mathematics or science course after successfully completing the last one. Tabulations of these transition percentages, based on a Department of Education analysis of the HS&B survey, appear in tables **2-6** and 2-7.

The data clearly show that females and minorities drop out of the normal sequence of courses. In mathematics, females drop out after taking algebra 11 and fail to take trigonometry; they also forgo physics after taking chemistry. Blacks and Hispanics similarly fall out after trigonometry, although fewer of them move from algebra to geometry than do whites. These disparities are stronger among the "high-talent" groups of those who earned As and Bs on the previous courses.

Table 2-6.—Percentage of 1982 High School Graduates Who Have Taken College Preparatory Mathematics Courses by Sex, and Race/Ethnicity

Subject	All	Males	Females	Asian	Black	Hispanic	White
Algebra I	63	61	65	65	53	54	66
Algebrall	31	31	31	44	22	19	34
Geometry	48	47	49	68	33	28	53
Trigonometry	7	9	6	16	4	5	8
Other advanced mathematics	13	14	13	30	5	7	15
Calculus	6	6	5	15	2	2	6

SOURCE U.S Department of Education, National Center for Education Statistics, "Science and Mathematics Education in American High Schools Results From the High School and Beyond Survey," NCES 84-211 b, Bulletin, May 1984, table A-5

Table 2-7.—Percentage of 1982 High School Graduates Who Have Taken College Preparatory Science Courses by Sex, and Race/Ethnicity

Subject	All	Males	Females	Asian	Black	Hispanic	White
General science	30	30	30	24	33	34	29
Basic biology	74	73	76	78	74	69	75
Advanced biology	8	7	9	13	6	5	9
Chemistry	24	25	24	41	19	13	27
Advanced chemistry	4	5	3	8	2	2	4
Geology	14	15	13	9	11	12	15
Physica I	11	15	8	27	6	5	13
Advanced physics	1	2	1	5	1	1	2
Unified science	28	30	26	17	34	21	27

SOURCE: U S. Department of Education, National Center for Education Statistics, "Science and Mathematics Education in American High Schools Results From the High School and Beyond Survey," NCES 84-211b, Bulletin, May 1984, tables A-4 and A-5

High-talent females drop out after algebra I, algebra II, and trigonometry. Very few high-talent Blacks take calculus, compared to whites, possibly indicating the paucity of calculus offerings in schools with high minority populations. Hispanics' persistence in science and mathematics course-taking is low throughout.

The data underscore the advantage students gain from attending suburban high schools rather than urban or rural ones. They also show a significant geographic disparity in persistence in mathematics and science course-taking. Persistence rates in the New England and Mid-Atlantic regions are some **50** or more percent higher than in West North Central, West South Central, and Mountain regions. (See figures **2-6** and **2-7.)**

These findings are supported by an analysis of data from the 1982 NAEP mathematics assessment, which found that, regardless of curricular track, racial composition of the school attended, grade or achievement level, Black and Hispanic students lagged in enrollments in advanced mathematics classes compared with their white peers."

Black enrollments in high school science courses vary significantly according to geographic region, parental expectations (especially those of mothers), and high achievement in other subjects such as English.[68] Black students in the Mid-Atlantic regions were more likely to take science courses, while those in the Pacific and the East South Central regions were least likely to take science courses.

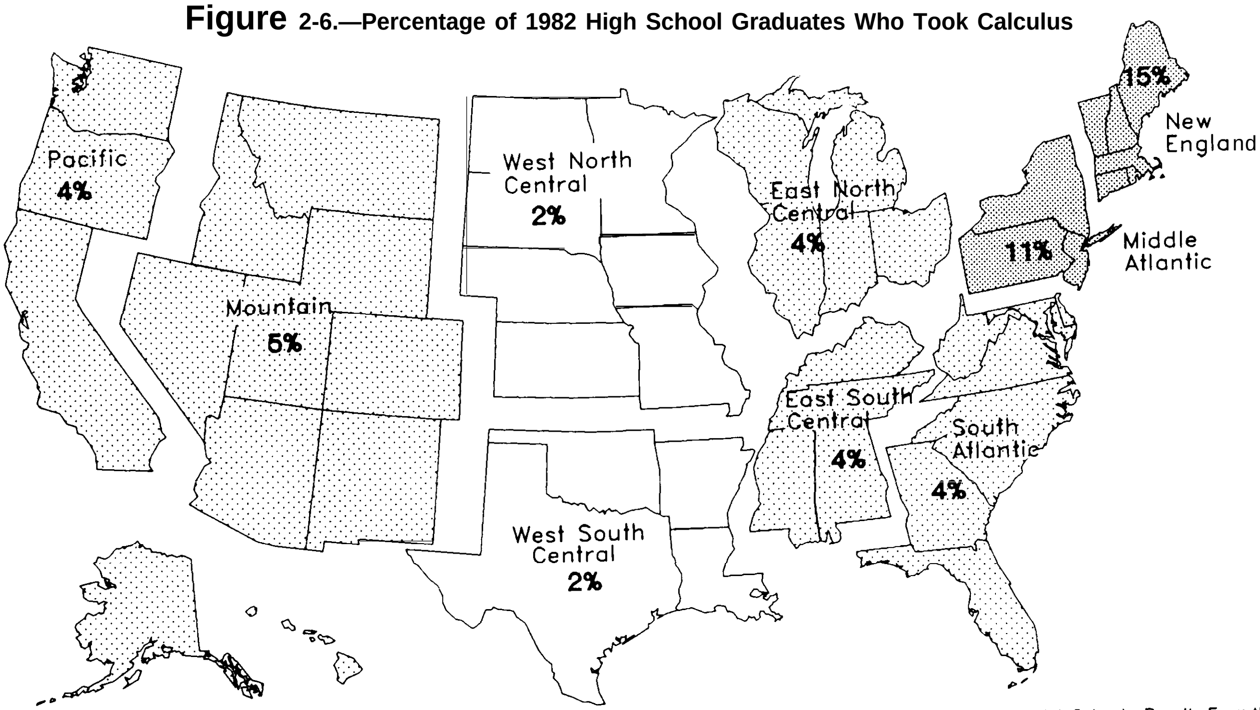
[67]Davis, op. cit., footnote, 57, p. 74.

[68]Ellen O. Goggins and Joy S. Lindbeck, "High School Science Enrollment of Black Students, " *Journal of Research in Science Teaching,* vol. 23, No. 3, 1986, pp. 251-261.

TRACKING AND ABILITY GROUPING

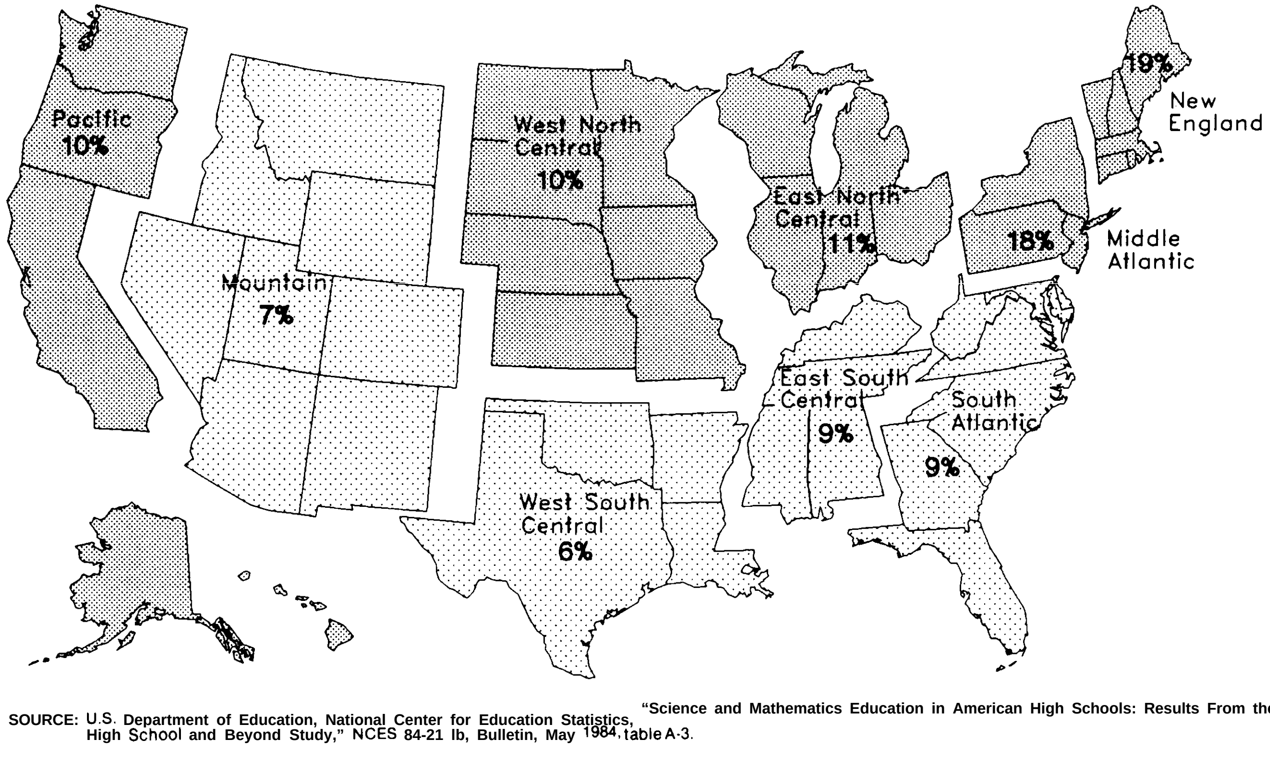
Ability grouping is practiced nearly universally in American schools. Guidance counselors and teachers sort students by ability as early as the third grade, using standardized tests and individual judgment. Students who display the conventional attributes of the potential scientist or engineer are encouraged to pursue the mathematics and science courses that will prepare them for

Figure 2-6.—Percentage of 1982 High School Graduates Who Took Calculus



SOURCE: U.S. Department of Education, National Center for Education Statistics, "Science and Mathematics Education in American High Schools: Results From the High School and Beyond Study," NCES 84-211b, Bulletin, May 1984, table A-4.

Figure 2-7.—Percentage of 1982 High School Graduates Who Took Physics



SOURCE: U.S. Department of Education, National Center for Education Statistics, "Science and Mathematics Education in American High Schools: Results From the High School and Beyond Study," NCES 84-21 lb, Bulletin, May 1984, table A-3.

these careers. Proponents claim that students interests are reinforced by exposure to those of their similarly enthusiastic peers. Others are directed toward other courses and careers. What we have here is a double-edged sword.

The Double= Edged Sword

Tracking or grouping is intended to help prevent the quick learner from trampling over the slow learner and the slow from delaying the progress of the quick. In short, tracking is supposed to give all students a fair chance (and help teachers maintain control). Comparisons and labels, however, are inevitable. Tracking is widely believed to both harm and help students' self--esteem, progress, achievement, socialization, and educational and vocational destinations. Because its effects are varied and not readily measurable, it has been a very difficult issue for educational researchers to study.

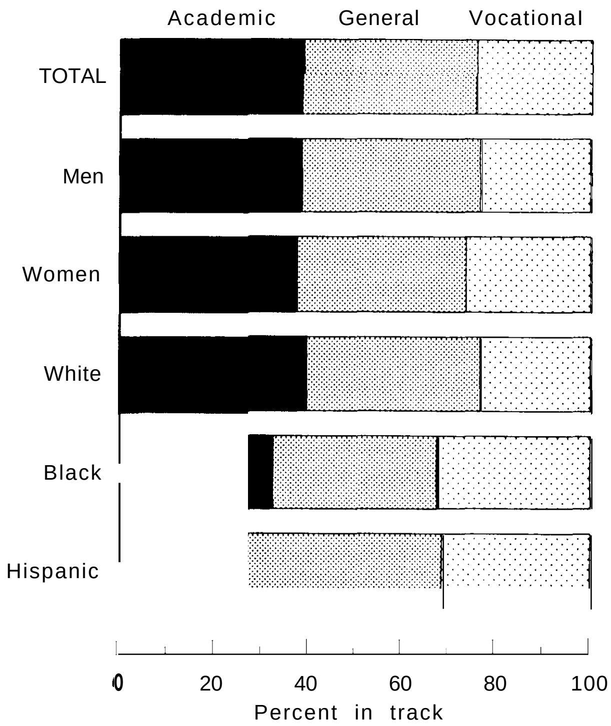
Many students' career options are narrowed by this sorting. Those who fail to display the signs of early promise, and those whose home life or idiosyncrasies place academic or social obstacles in their paths, may find themselves shunted aside from the mathematics and science preparation that makes possible further study of science or engineering. Many of these students have the ability and the desire to pursue these careers. About one-quarter of those who go on to major in science or engineering were in a nonacademic track in high school. Generally, their relatively poor mathematics and science preparation makes it difficult for them to keep up in college, and they are at risk of attrition. Thus, ability grouping, if applied too clumsily or rigidly, may lead to the waste of talent.

Minority leaders, both within and outside the education community, have complained that tracking perpetuates racism, The evidence is that the practice is a structural impediment to students' progress to advanced study in science and engineering. Nevertheless, inconsistencies in definitions between surveys that include information on tracking often yield misleading comparisons. In particular, it is not possible to state with any certainty whether enrollments in the academic or general tracks, either in total or by race or gender, are declining through time. Figure **2-8,** taken from High School and Beyond data, shows the proportion of students, by race and gender, that were enrolled in each high school curriculum track in 1982, but these data are not necessarily consistent with other surveys.[69] It is clear, however, that students are enrolling in courses in much more varied patterns than they used to: they frequently mix courses designed for the general, vocational, or academic track. To this extent, the stranglehold of tracking is loosening.

The principal objection to tracking or ability grouping is that it can become a self-fulfilling prophecy, changing the behavior of students, students' peers, teachers, and parents toward members of a particular group. For slow-tracked students the technique stifles aspiration by rein-

[69] Similar data are reported in Davis, op. cit., footnote 57, p. 23, based on the National Assessment of Educational Progress (NAEP) 1981-82. More recent data from the 1985-86 NAEP mathematics assessment put the proportion of 17-year-olds enrolled in the academic track at *52* percent, in the general track at *38* percent, and in the vocational track at only 10 percent. Dossey et al., op. cit., footnote *18,* p. 119.

Figure 2.8.—Track Placement by Race/Ethnicity and Sex, High School Graduates of 1982



SOURCE U S Department of Education, High School and Beyond survey.

Photo credit: William Mills, Montgomery County Public Schools

Science-intensive schools often have sophisticated, costly equipment.

forcing feelings of low status and, worse, by feedingstudents' beliefs that they have been left behind and can never catchup. It deprives this group of the stimulation provided by high achievers, which can help promote development of the behavior and skills of learning. Some writers have suggested that grouping and tracking is a primary means of maintaining the status quo, preventing the upward mobility of the poor and minorities and excluding them from preparation for professional occupations such as science and engineering. 70

[70]Bruce R. Hare, "Structural Inequality and the Endangered Status of Black Youth, " ***Journal of Negro Education, vol. 56, No. 1, 1987,*** pp. 100-110; Joel Spring, ***The American High School 1942-1985: Varieties of Historical Interpretation of the Foundations and Development of American Education (New*** York, NY: Longman, 1986); and William Snider, "Study Examines Forces Affecting Racial Tracking, " ***Education Week, Nov.*** 11, 1987, pp. 1, 20.

Effects of Grouping Practices

For all the controversy, research on the effects of grouping is far from conclusive, even when it uses simple output measures such as achievement scores. This inconclusiveness might be taken as evidence that other important factors, such as students' socioeconomic status and teaching quality, are more important in predicting educational outcomes than the existence of tracking.

Research on the effect of ability-based grouping practices in elementary schools has found that grouping makes little or no difference to the most able students, but does have a considerable retarding effect on the less able students. [71] A 1968

[71] Robert E. Slavin, "Ability Grouping and Student Achievement in Elementary Schools: A Best-Evidence Synthesis, " prepared for

study of tracking in secondary schools by the National Education Association found that for each study that showed a gain in achievement scores across the ability spectrum another study showed a net loss. The exception was the lowest ability level, which had uniformly slightly more losses than gains .72

To examine the effects of tracking on students intending majors in science and engineering, OTA used the High School and Beyond database.[73] In the survey's random sample of about ***12,000*** high school sophomores in ***1980, 25*** percent of those students planning science and engineering majors by their senior year and scoring above average on the HS&B achievement test had been enrolled in the general and vocational tracks. Compared with their academically tracked peers, this group was of lower socioeconomic status and had a slightly lower average achievement test score. By the end of high school, they had taken about one less mathematics course and their overall grade point average was about one-quarter of a point lower. Their average SAT score was about **68** points lower. They were less likely to go to college and more likely to enroll in a junior college than members of the academically tracked group. Table **2-8** displays some characteristics of the two groups .74

Table 2"8.—Science-Intending Students Among High School Graduates of 1982, by Track

Characteristics	Group from nonacademic tracks N = 428	Group from academic track N = 1,147
Demographic characteristics:		
Percent Black.	3	5
Percent Hispanic	6	5
Percent female	40	41
High school experiences:		
Score on HS&B Achievement Test[a]	55.9	59.2
Number of advanced mathematics courses taken	2.0	3.1
Average high school grade point average	2.8	3.0
Score on mathematics portion of the SAT or ACT[b]	457	*525*
College experiences:		
Percentage who had enrolled in college by February 1984	67	*89*
Percentage in 2-year colleges.	47	*24*
College grade point average	2.8	*2.9*

KEY: HS&B = High School and Beyond survey
SAT = Scholastic Aptitude Test
ACT = American College Testing program
[a]On HS&B **Achievement Test, mean score= 50. standard deviation= 10**
[b]Scores **are normalized to those for the SAT, with a range of** 0 **to** 800

SOURCE: Valerie Lee, "Identifying Potential Scientists **and Engineers An Analysis of the High School-College Transitlon," OTA contractor report, September 1987; based on the High School and Beyond survey**

Other data indicate that academically tracked 17-year-olds are more than twice as likely than those in other tracks to survive to algebra II in the normal sequence of high school mathematics courses, and about five times as likely to survive to pre-calculus or calculus .75 Tracking does have some positive effects on the academically tracked science-intending stream, however, for it generally ensures their continuing participation and preparation in the science and engineering pipeline, by increasing the probability that they will take pipeline mathematics and science courses.

For those who run afoul of the system—by reason of race, class, attitude, or bias—access to high-quality, academic mathematics and science

the U.S. Department of Education, Office of Educational Research and Improvement, Grant No. OERI-G-86-OO06, June 1986.

[72]Robert E. Fullilove, "Images of Science: Factors Affecting the Choice of Science as a Career," OTA contractor report, 1987. The National Education Association study is quoted in James E. Rosenbaum, "Social Implications of Educational Grouping, " Review *of* ***Research in Education,*** David Berliner (cd.), vol. 8 (Itasca, IL: F.E. Peacock Publishers, 1980), pp. 361-401. For other research, see Glenna Colclough and E.M. Beck, 'The American Educational Structure and the Reproduction of Social Class, " ***Sociological Inquiry, vol. 56, No.*** *4,* fall 1986, pp. 456-476; Beth E. Vanfossen et al., "Curriculum Tracking and Status Maintenance, " Sociology *of Education,* ***vol. 60,*** April 1987, pp. 104-122; and Gerald W. Bracey, "The Social Impact of Ability Grouping, " *Phi Delta Kappan,* May 1987, pp. ***701-702.***

[73]Lee, op. cit., footnote 58.

[74]A regression analysis indicated that, for these students, track placement was a stronger predictor than class, race and ethnicity, or gender of the number of academic mathematics courses that students took in high school. From a national perspective on the production of scientists and engineers, this finding attests to the centrality of students' preparation in high school mathematics. An important new national longitudinal survey being conducted by Jon Miller at Northern Illinois University, funded by the National Science Foundation, should disentangle many of the influences of early mathematics and science learning. The study is following a cohort from grade eight onwards, and is surveying family, social, and school variables that might affect science and mathematics learning, attitudes, and behaviors.

[75]Dossey et al., op. cit., footnote 18, table 8.3.

courses is lost and their expectations are dulled. Nevertheless, the academic track is not the right place for all students. A corollary problem is the early age at which tracking occurs, putting many students at a considerable disadvantage when they enter middle and high school. The need is for systems to practice tracking efficiently but flexibly.

Science Education and Track= Busting

In the context of science and mathematics education, the "efficiency" and "flexibility" of tracking may be incompatible with the notion—and today the more commonly heard prescription—of "science for all. "

> Unless students very early acquire both a basic conceptual science vocabulary and a zest for learning and problem solving, they are extremely unlikely to take science courses—or to succeed if they do. . . . [Needed, then, is] a baseline science curriculum that will provide all students with a consistent and coherent overview and an integrated body of knowledge during the elementary and high school years.[76]

What may appear to be "special pleading" for science and mathematics might then also be seen as one rationale for "track-busting. " Put another way, a change in expectations of students' capability will have to precede changes in both teaching and learning.

"George W. Tressel, "Priestley Medal Address" (letter), ***Chemical & Engineering News,*** Sept. 19, 1988, pp. 3, 39. Also see George W. Tressel, "A Strategy for Improving Science Education, " presented to the American Educational Research Association, Apr. 8, 1988.