REPORT BY THE U.S.

General Accounting Office

New Directions For Federal Programs To Aid Mathematics And Science Teaching

GAO does not find evidence that training programs to upgrade existing science and mathematics teachers will improve teaching effectiveness. Such programs are a prominent part of proposed federal legislation.

Teacher shortage problems, which are also addressed in the proposed legislation, may be easier to solve. Programs to retrain teachers of other subjects to teach mathematics and science classes seem to be one viable solution to technical teacher shortages.

Gaps in the information available to policymakers are so severe that GAO could not determine (1) if there are net nationwide shortages of science and mathematics teachers and (2) if the quality of technical teaching has declined in recent years.

GAO/PEMD-84-5
MARCH 6, 1984

UNITED STATES GENERAL ACCOUNTING OFFICE
WASHINGTON, D.C. 20548

PROGRAM EVALUATION
AND
METHODOLOGY DIVISION

B-214382

The Honorable T. H. Bell
Secretary of Education

The Honorable Edward A. Knapp
Director, National Science Foundation

The report discusses proposed solutions to perceived problems of quantity and quality in the teaching of mathematics and science in the public schools. Also discussed is proposed legislation which may be administered by your agency. Chapter 6 contains observations which include matters relevant to the administration of this legislation and possibly other agency initiatives in science and mathematics education.

We are sending copies of this report to the Director, Office of Management and Budget, to the Director, Office of Science and Technology Policy, and to the cognizant congressional appropriation and authorization committees.

Eleanor Chelimsky
Director

D I G E S T

The status of mathematics and science education in the public schools became a major issue by 1983. GAO synthesized past evaluation and research studies and used other methodologies to examine (1) the nature of the problem and its remedies, (2) the prospects for upgrading existing mathematics and science teachers, (3) the viability of retraining teachers of other subjects to teach science and mathematics, and (4) priorities for evaluation in mathematics and science teaching.

WHAT IS THE NATURE OF THE MATHEMATICS AND SCIENCE TEACHING PROBLEM?

If the sweeping reexamination of mathematics and science education in the 1950's was fundamentally driven by national security concerns, national attention in the 1980's seems powered by international economic competition. Continued high levels of unemployment and visible losses of automobile and consumer electronics markets, for example, have fueled proposals for action.

Some observers link national economic prosperity to improved science and mathematics education aimed at achieving growth through technology, but others have opposing views of the goals of education and place different emphases on the educational needs of the future United States work force. The apparent national consensus on the need for educational reform thus obscures significant disagreement with regard to the dimensions and direction of that reform. Critics differ in their emphasis on mathematics and science as opposed to other subjects and on the education of the elite (or most able) as opposed to the education of all students. Even within the fields of mathematics and science education alone, it is difficult to pursue goals of improving education for the most able and the average student simultaneously. To do so would be to increase the need for more teachers, which may require

relaxing standards, and to increase the need for better teachers, which may require raising standards. (pp. 7-10)

Those who place priority upon technical education are concerned over evidence of problems with the quantity and quality of mathematics and physical science teachers in the United States public schools:

--42 out of 45 responding states reported a mathematics teacher shortage in 1982;

--surveys show a drop of 64 percent and 33 percent in mathematics education and science education graduates, respectively, from 1971 to 1981, although reduced enrollments had cut the production of new teachers 39 percent across all fields;

--about half of recent bachelor degree graduates who are teaching science and mathematics are not certified or eligible for certification in the field they are currently teaching. (pp. 10-14)

Legislation to upgrade science and mathematics education--House of Representatives 1310 and Senate 1285--is being considered by the Congress. (pp. 14-18)

WHAT ARE THE PROSPECTS FOR IMPROVING THE EFFECTIVENESS OF TEACHING THROUGH TRAINING TO UPGRADE EXISTING MATHEMATICS AND SCIENCE TEACHERS?

GAO does not find evidence that training programs to upgrade existing mathematics and science teachers will produce results in terms of improved student achievement.

GAO first examined the prospects of such training programs by reviewing the experience of teacher institutes funded by the National Science Foundation (NSF) from the mid-1950's to the early 1970's. A search for studies of the impact of teacher attendance at these institutes upon the subsequent academic achievement of students of the participating teachers produced only one study that met GAO's minimum criteria, and it showed mixed results. (pp. 22-25 and 31-32)

GAO then searched for related evidence, focusing on the fact that subject matter training was a major element of the NSF institutes. The general research in the 1970's failed to show any consistent relationship between the extent of teachers' knowledge and subsequent student learning. (pp. 32-34)

More recent "process-product" research suggests that student performance can be improved by training teachers to manage instructional programs and student behavior. The results of this emerging research area are promising, but process-product research has not yet focused on the secondary school level. (pp. 34-36)

HOW VIABLE A SOLUTION TO SHORTAGES OF MATHEMATICS AND SCIENCE TEACHERS IS RETRAINING TEACHERS CERTIFIED IN OTHER FIELDS?

GAO finds that programs to retrain teachers from other subjects to teach science and mathematics classes seems to be one viable solution to the technical teacher shortage. Early results from 11 programs show that teachers apply for admission, enroll, and are starting to complete retraining programs. There is little reason to doubt that most program graduates will become certified mathematics or science teachers. (pp. 51-55)

It is too early to determine the quality of retrained teachers, but obtaining certification indicates a threshold of quality. The results reported in the previous section suggest that further upgrading of teacher quality may not lead to improved student achievement.

GAO finds that retraining programs sponsored by state education agencies (SEA's) and local education agencies (LEA's) tend to have higher retention rates than university programs. SEA and LEA programs provide funding for selected teachers to attend college classes, while retraining programs fully controlled by universities charge full tuition and do not systematically provide student financial assistance. The greater success of SEA and LEA programs seems to be due to a combination of the funding provided and their more stringent selection process. (pp. 46-52)

Tear Sheet

The Houston school district appears to have been remarkably successful in alleviating the shortage of certified technical teachers. Retraining programs combined with other incentives and bonuses contributed to a sharp reduction in the secondary science and mathematics teacher shortage between 1978 and 1982.

GAO finds wide variation in the length of time to complete retraining programs ranging from 9 months to 3 years. Shorter programs insist on more mathematics or science courses as admission requirements and provide for full-time attendance during at least part of the program. (pp. 50-53)

WHAT WILL BE NEEDED TO IMPROVE EVALUATIONS OF THE QUALITY AND QUANTITY OF MATHEMATICS AND SCIENCE TEACHING?

Data do not exist to determine with confidence whether or not there is a net nationwide shortage of mathematics and physical science teachers. Information on the quality of mathematics and science teachers--and whether or not the quality of technical teaching has declined--is also flawed. (pp. 10-14)

In addition to improved data on these critical issues, GAO poses evaluation questions for consideration in the areas of both quantity and quality of mathematics and science teaching. (pp. 57-63)

OBSERVATIONS

1. GAO's analysis raises questions about approaches to upgrade the quality of mathematics and science teaching that have substantial teacher training components. This report suggests that programs geared at upgrading existing mathematics and science teachers may not produce results in terms of improved student achievement. Upgrading training may be best focused upon uncertified teachers now in or coming into the mathematics and science classrooms. Past research may not be germane to this group. This approach would differ from the prior NSF strategy and would require careful planning for successful NSF implementation. It may be more productive to concentrate resources upon filling mathematics and

science teacher vacancies. GAO found evidence that retraining programs are one viable solution to the technical teacher shortage. The quantity or shortage problem may be more successfully dealt with because it is a simpler problem. (pp. 65-66)

2. Programs to retrain teachers for mathematics and science classrooms are highly variable in length but can be controlled by policy intervention. Shorter, full-time retraining programs can produce certified teachers sooner, but full-time programs will be more costly, since they involve both scholarship and subsistence costs for the teachers being retrained plus salary expenses for replacement teachers during the retraining period. In the absence of scholarship and subsistence payments, full-time programs seem to attract few students. (p. 66)

3. The strategy in the proposed mathematics and science legislation of requiring linkage between universities and school districts in training and retraining programs may be productive since the SEA and LEA retraining programs tend to experience higher retention rates than university programs. (pp. 66-67)

4. The efforts of process-product researchers to identify effective teaching behaviors and to develop teacher training programs around those findings offer promising possibilities for consideration by the Department of Education and other funding sources. The approach has been limited to mathematics and reading and could be attempted in science teaching. Since the bulk of the effort has been conducted at the elementary grade levels, it may be useful to devise a secondary level research program. (p. 67)

5. Data are not available to determine whether or not there is a net shortage of mathematics and science teachers or to assess the quality of teaching in those fields. There are two corresponding information needs which result. First, with respect to the size of any shortage, is the need for adequate data at both the national and state levels on the extent of the shortfall by subject each year. Second, with respect to quality, is the need for an adequate assessment of the knowledge levels of mathematics and science teachers and whether or not

they are out-of-date in their subject areas. These information gaps hinder both the enactment and administration of effective federal remedies and retard appropriate evaluation of the success of new federal remedies.

Limited evaluation support provided to the programs in the proposed federal mathematics and science education aid bills, combined with budgetary pressure limiting the availability of other agency funds, suggest that it may never be known whether or not those programs are effective. (pp. 67-68)

AGENCIES' COMMENTS AND GAO'S RESPONSE

NSF, the Department of Education, the Office of Science and Technology Policy, and the Office of Management and Budget commented on a draft of this report. The agencies generally characterized the report as useful and addressed to issues of major importance.

The agencies raised a concern about GAO's finding that programs to upgrade science and mathematics teachers are not likely to produce results in terms of improved student achievement. The few facts cited against this finding, however, gave GAO no reason to alter the report. The agencies generally agree with GAO's observations on the need to remedy the lack of evaluative information for shaping effective federal programs to improve mathematics and science education. (app. III)

Contents

ABBREVIATIONS

BSCS	Biological Science Curriculum Study
GAO	U.S. General Accounting Office
LEA	Local Education Agency
NSF	U.S. National Science Foundation
SEA	State Education Agency
SMSG	School Mathematics Study Group

CHAPTER 1

INTRODUCTION

The status of mathematics and science education in the public schools became a major issue in 1983. Concerns were raised over the level of student achievement in these subjects and over the shortages of teachers certified to teach mathematics and science in secondary schools. The dialogue over mathematics and science education expanded into a wider review of the quality of teaching and the quality of our schools. Numerous commissions issued reports recommending a variety of educational reforms. The Congress considered legislative proposals for federal assistance for mathematics and science education.

In this report, we address four science and mathematics education issues:

--the nature of the problem and its remedies;

--the prospects for upgrading existing mathematics and science teachers;

--the prospects for reducing the mathematics and science teacher shortage by retraining teachers from other subject areas; and

--the current ability to evaluate the quantity and quality of mathematics and science teaching.

We then make observations on the implications of our work for mathematics and science education legislation. Our report utilizes the evaluation synthesis and other methodologies. Its purpose is to provide information to the Congress in continuing debates over improving mathematics and science education, to education policymakers at all levels of government, as well as to the education profession.

BACKGROUND

Some three decades ago, this country became alarmed over the status of mathematics and science education and our ability to keep pace technologically with the Soviet Union. The release of a 1955 report, Soviet Professional Manpower by Nicholas DeWitt, detailing Russian scientific advances, and the subsequent launching of Sputnik I by the Soviet Union in 1957 stirred demands for more education in the sciences.[1] While extensive documentation was not available, there was widespread agreement that there were scientific and technical manpower shortages. How could those shortages be eliminated? There was evidence that about half the most able high school students were not entering college. It was argued that many students did not enter college in technical fields because of problems of poor teacher preparation and obsolete curricula.[2] One answer to poor teacher preparation by the

then recently created National Science Foundation (NSF) was a program of summer instruction for high school teachers.[3]

Another major federal initiative, the National Defense Education Act of 1958, authorized a variety of activities including the purchase of laboratory equipment, upgrading guidance and counseling services, improvement of foreign language teaching, and improvement of education statistics, among others.[4] In the 1960's, federal education aid moved toward a concern with equality of educational opportunities for the poor and for racial and language minorities. In the 1970's, in the wake of university student protests about curriculum content, among other things, educators became concerned over the relevance of education. Schools experimented with ways of increasing student choice of courses, reducing competition among students in an attempt to individualize educational experiences, and increasing the influence of students and parents in school decisionmaking.

By 1983, the status of mathematics and science education in the public schools again emerged as an issue. Among the most frequent concerns raised are

--declining student achievement test scores in mathematics and science. The widely used Scholastic Aptitude Test, for example, shows a steady and appreciable decline in the mathematics subscore from 1962-64 to 1980. The National Assessment of Educational Progress found a steady decline in the science achievement of 17-year-olds since the initial testing in 1969, although some other tests show student science achievement to be more stable.[5] There is some evidence that the declines may have bottomed out, but they have not yet reversed.[6]

--reported shortages of teachers in mathematics and some science fields. The Department of Education found shortages of technical teachers, such as a shortage of 900 mathematics teachers and 600 physical science teachers as early as 1979.[7] A survey of college placement officials published in 1983 found a considerable shortage of teachers in mathematics, physics, and chemistry.[8]

--the apparent decline of American technology from its preeminence in the 1960's. Many technology-based industries are now in second or third place vis-a-vis foreign rivals; this has focused attention on our mathematics, science, and engineering capabilities.[9]

A succession of reports by commissions and others made recommendations on mathematics and science education either centrally, as in the case of the National Science Board Commission on Precollege Education in Mathematics, Science, and Technology, or as part of a broader review of the quality of teaching and schooling. Some of the more prominent examples of the latter are

the reports of the National Commission on Excellence in Education and the Task Force on Education for Economic Growth.[10]

On March 2, 1983, the House passed House of Representatives 1310, the Emergency Mathematics and Science Education and Jobs Act. The Senate is also considering similar legislation, Senate 1285. Both bills authorize a variety of programs for improving mathematics and science education, which we will review in chapter 2.

OBJECTIVES, SCOPE, AND METHODOLOGY

The four study questions we develop in this report are listed in table 1. The first question--what is the nature of the

Table 1

Mathematics and Science Education Questions and Subquestions

QUESTION		SUBQUESTION	
1-0	What is the nature of the mathematics and science teaching problem?	1-1	What will be the effect of new technologies on the need for science and mathematics education?
		1-2	What are the problems in the quantity and quality of mathematics and science teachers?
		1-3	What remedies have been proposed for these problems?
2-0	What are the prospects for improving the quality of teaching through training to upgrade existing mathematics and science teachers?	2-1	What was the extent and nature of participation in the NSF institute program?
		2-2	How effective were the NSF institutes?
		2-3	Are more knowledgeable teachers more effective?
		2-4	What does recent classroom research tell us about how to improve student achievement?
3-0	How viable a solution to shortages of mathematics and science teachers is retraining teachers certified in other fields?	3-1	What are the characteristics of the new retraining programs?
		3-2	How effective are the new retraining programs?
4-0	What will be needed to improve evaluation of the quality and quantity of mathematics and science teaching?	NONE	

mathematics and science teaching problem?--is largely conceptual. Rather than repeat the exhaustive recitation of the problem that is available elsewhere, we introduce the problem and frame it in the context of concerns about United States economic strength.[11] We note the quantity and quality components of the teaching problem and note other school improvement approaches. We limit this report to the public schools because of the difficulty in obtaining data on private schools.

The second question--what are the prospects for improving the quality of teaching through training to upgrade existing mathematics and science teachers?--involves a synthesis of evaluations from NSF teacher institute programs that spanned two decades. We chose to examine this issue because past NSF experience with training to upgrade mathematics and science teachers could have an important practical application since such upgrading is a prominent feature of the proposed legislation. We discuss our methodology of searching for and selecting evaluation studies in chapter 3. Studies on the extent and nature of participants drawn to such programs and the available evidence on effectiveness worthy of use in congressional decisionmaking are reviewed. We then draw on a body of related research dealing with the links between teachers' knowledge and the achievement gains of their students. More recent approaches emphasizing effective teaching through systematic classroom management are then assessed. The major limitation of this approach is the weakness of the evaluation studies of the NSF institutes.

The third question seeks to determine the viability of retraining teachers certified in other subject areas as a remedy to the shortage of mathematics and science teachers. We chose to examine this issue because it was the emphasis of the administration bill (which was introduced but not yet acted upon by either the House or the Senate) and because some retraining programs are being operated through nonfederal funding sources. Our approach began with a literature search but the recency of these programs signifies a paucity of available data and literature. We turned instead to identifying a sample of such programs, using a methodology we describe in chapter 4. We then explored these programs through telephone interviews supplemented by available written materials provided by directors of the programs. Since these programs are too new to make effectiveness or impact evaluations possible, the focus of our data collection was upon the program goals, length of the programs, and evidence of feasibility or plausibility of the programs to date as one solution to the problem of the quantity of mathematics and science teachers.

The fourth question--how can the quality and quantity of mathematics and science teaching be evaluated effectively?--concerns an issue that repeatedly troubled us during the conduct of this review. The availability of information on the extent of needs in the quality and quantity of mathematics and science teaching is a fundamental prerequisite to sound public policy

planning. Our method here draws upon our experience in addressing the other study questions and upon the developments in the field of program evaluation.

We discuss the questions in the order in which they appear in table 1 and in the preceding discussion. Finally, in the last chapter we draw together the findings of this review to form observations for the implementation of new federal mathematics and science education legislation.

NOTES

[1]Nicholas DeWitt, Soviet Professional Manpower (Washington, D.C.: National Science Foundation, 1955). See also Milton Lomask, A Minor Miracle: An Informal History of the National Science Foundation (Washington, D.C.: National Science Foundation, 1976), p. 122.

[2]Harvey Averch, "Models and Programs in Science Education, 1959-1976," NSF Program Report, 1 (June 1977), 6.

[3]Langdon Crane, The National Science Foundation and Pre-College Science Education: 1950-1975 (Washington, D.C.: Congressional Research Service, 1975).

[4]Forbis K. Jordan, Precollege Science and Mathematics Education: Experiences with the National Defense Education Act and the Teacher Institutes Conducted by the National Science Foundation (Washington, D.C.: Congressional Research Service, December 15, 1982), pp. 4-6.

[5]Lyle V. Jones, "Achievement Test Scores in Mathematics and Science," Science, July 24, 1981, pp. 412 and 414-16. There is some evidence that high school seniors who plan to attend college and major in science or mathematics changed little in science or mathematics achievement from 1973 to 1979.

[6]Betty M. Vetter, "Supply and Demand for Science and Math Teachers," prepared for "Myths, Realities, and Research," National Institute of Education conference on teacher shortage in science and mathematics, Washington, D.C., February 8-10, 1983, p. 16.

[7]Teacher Layoffs, Shortages in 1979 Small Compared with Total Employed (Washington, D.C.: National Center for Education Statistics, U.S. Department of Education, October 16, 1981), p. 5.

[8]"Databank," Education Week, February 16, 1983, pp. 16ff.

[9]Jordan D. Lewis, "Technology, Enterprise, and American Economic Growth," Science, March 5, 1982, p. 1204.

[10]National Science Board Commission on Precollege Education in Mathematics, Science and Technology, Educating Americans for the

21st Century (Washington, D.C.: National Science Board, National Science Foundation, 1983); National Commission on Excellence in Education, A Nation at Risk: The Imperative for Educational Reform (Washington, D.C.: U.S. Government Printing Office), 1983; Task Force on Education for Economic Growth, Action for Excellence (Denver: Education Commission of the States, 1983).

[11] Science and Engineering Education for the 1980's & Beyond (Washington, D.C.: National Science Foundation and U.S. Department of Education, 1980).

CHAPTER 2

WHAT IS THE NATURE OF THE MATHEMATICS AND SCIENCE TEACHING PROBLEM?

In this chapter, we introduce the context of the concern over mathematics and science education, especially the issue of what technical education needs the United States may have in order to secure our future in international economic competition. This is not, of course, the only goal of technical education; however, the role of technical education in advancing economic growth is the connection with this chapter.

We find that the apparent national consensus on the need for educational reform obscures significant differences in perceptions of educational priorities necessary to achieve greater economic growth. We find that many problems raised about the state of mathematics and science education can be classified as pertaining to either the quantity or quality of teaching. We review the evidence on problems in both the shortage (or quantity) and the quality of mathematics and science teachers. We summarize the remedies to those problems proposed in federal legislation as well as by state and local educational agencies.

WHAT WILL BE THE EFFECT OF NEW TECHNOLOGIES ON THE NEED FOR SCIENCE AND MATHEMATICS EDUCATION?

If the sweeping reexamination of mathematics and science education in the 1950's was fundamentally driven by national defense concerns, national action in the 1980's seems powered by international economic competition. Continued high levels of unemployment and visible losses of automobile and consumer electronics markets to foreign competition have fueled proposals for action, which include upgrading mathematics and science education. Since the nature of the mathematics and science education remedies is so closely linked to the nature of the perceived problem, in this section we examine different directions or models of future economic change and their educational implications. This analysis shows that there are great differences in views about what the future mix of jobs will be.

High tech model

The high tech model suggests that growth in high technology industries is one solution to our economic problems. President Reagan said in his state of the union address on January 25, 1983,

> "as surely as America's pioneer spirit made us the industrial giant of 20th century, the same pioneer spirit today

> is opening up another vast frontier of opportunity--the frontier of high technology. In conquering the frontier we cannot write off our traditional industries, but we must develop the skills and industries that will make us a pioneer of tomorrow."[1]

The Task Force on Education for Economic Growth predicts that "the conditions that concern us today--swiftly advancing technology; economic competition in a global arena; the sudden obsolescence of skills--will be even more intense tomorrow."[2] The advance of technology in the workplace will extend, the Task Force argues, from word processors in offices to sophisticated weapons systems in the armed forces to replacing lift operators with computerized conveyor system operators.[3]

In congressional debate over the mathematics and science education legislation, Congressman Ford of Michigan observed that

> "Management analyst Peter Drucker predicts that through the next two decades 10 to 15 million manufacturing jobs will disappear in America. . . . [I]t is clear that the new jobs will be in areas such as computer technology, robotics, fiber optics, genetic engineering and health care."[4]

Congressman Ford continued, noting shortages of trained and skilled workers in the labor force:

> "Shortages already exist or are anticipated for engineers, nurses, computer service technicians, and machinists, among others. For example, the American Electronics Institute estimates that industry will need nearly 200,000 new engineers by 1985; while universities, given their current faculty, can supply only 70,000. . . . The Defense Department estimates that its contractors will need 71,000 more computer specialists, 61,000 more electrical engineers and 110,000 more machinists, tool and die makers and metal molders by 1987."[5]

Educationally, this model suggests more training in mathematics, computer science, and technical applications throughout the labor force.[6] Thus, schools must reverse the decline in student achievement in mathematics and science as well as upgrade the mathematics and science curricula and teacher preparation. The concern is not limited to the elite future leaders in science and technology but extends to a concern over upgrading the scientific literacy of the population more generally. Lagging student achievement in science and mathematics has led to the fear that "We are raising a new generation of Americans that is scientifically and technologically illiterate."[7] The high tech model is the intellectual underpinning of the proposed federal legislation to provide aid for mathematics and science education.

Minimal high tech model

Others argue that the impact of high technology on America's economic future has been overstated. While the percentage growth in some high tech occupations may be dramatic, the fact that these occupations are now relatively rare means that even a large percentage increase will translate into a modest number of new jobs. For example, while jobs for computer systems analysts may increase by over 100 percent from 1978 to 1990, only 200,000 new jobs will result. In contrast, over 600,000 new janitorial jobs will be created. There will be more new janitorial jobs than the combined total of new jobs in the five occupations with the highest percentage growth rates. These observers also argue that the impact of high tech in transforming existing jobs is being exaggerated or even distorted. As examples, they point to word processors as reducing needed skills for office work and to technological advances in printing as reducing the skill levels of those who remain in newspaper composing rooms.[8]

Educationally, we would expect under this model somewhat more limited concern over mathematics and science education advances. Mathematics and science education concerns present would logically be centered about the elite--an admittedly sizable elite, but an elite nonetheless--that will be needed to secure the high tech side of our future. Other educational implications would vary depending upon the observer's vision of the economic future.

Learning to learn model

Finally, it has been argued that the crucial growth of productivity depends on the utilization of knowledge from all sources to meet needs. Technological progress may make new achievements possible but a nation's economic strength is more dependent on the ability of its business firms to "reach out and grasp tomorrow's technologies and markets before competitors."[9] At the same time, firms must strive to "improve today's products and production processes."[10] The latter consists of numerous modest changes "some from short-term R&D but most from experience with the technology . . . to better satisfy market requirements."[11] The increasing need for effective technological innovation suggests a value of interdisciplinary collaboration under conditions that encourage the flow of new ideas and the ability to confront and work through differences.[12]

How do you educate for grasping tomorrow's technologies while improving today's products and production processes? The Task Force on Education for Economic Growth links education needs to four types of jobs. First, unskilled jobs such as hauling and janitorial work can be performed by people with less than today's basic skills. Second, basic jobs such as clerks in noncomputerized stores require today's basic education. Third, "learning-to-learn" jobs including most factory and service industry jobs will require teaching people how to acquire new skills of

analysis and problemsolving. Fourth, professional jobs require "learning-to-learn" skills and more sophisticated intellectual skills as well. Real chances for upward mobility "will increasingly be reserved for those with 'learning-to-learn' skills: not just the ability to read, write and compute at a minimal level, but more complex skills of problem solving, reasoning, conceptualizing and analyzing."[13] It is such general skills, rather than specialized training, that are proposed for a future in which work requirements are expected to change abruptly, and it will become increasingly difficult to predict beyond general trends what specific jobs will be in demand.[14]

Educationally, all this suggests the need to "raise both the floor and the ceiling of achievement in America, improving educational attainment for the most able students and for other students as well."[15] The Task Force on Education for Economic Growth calls for upgrading basic skills. Competency in reading may well extend beyond literal interpretation to include the ability to analyze and summarize as well as to interpret passages inferentially. Mathematical competency may well come to include more complicated computing and problemsolving skills. Writing competency may capture the ability to gather and organize information coherently.[16]

The National Commission on Excellence in Education reached a similar conclusion, arguing that recent efforts to improve mathematics and science education are

> "but a start on what we believe is a larger and more educationally encompassing need to improve teaching and learning in fields such as English, history, geography, economics, and foreign languages. We believe this movement must be broadened and directed toward reform and excellence throughout education."[17]

It may be observed from the above discussion of recent reports that the apparent national consensus on the need for educational reform obscures significant differences in perspectives on the future educational needs of this nation. These perspectives place varying emphasis on technological as opposed to other subjects and on education of an elite as opposed to that of all students. Even within the fields of mathematics and science education alone, it is difficult to pursue goals of improving education for the elite and the average student simultaneously. To do so would be to increase the need for more teachers, which may require relaxing standards, and to increase the need for better teachers, which may require raising standards.

WHAT ARE THE PROBLEMS IN THE QUANTITY AND QUALITY OF MATHEMATICS AND SCIENCE TEACHERS?

Many of the problems raised about the state of mathematics and science education in the elementary and secondary schools

can be classified as pertaining to the quantity or quality of teaching.

Quantity

One major concern was the evidence of shortages of secondary school teachers in mathematics and some science subjects. An annual survey of college placement officials found that the officials believed that there were teacher shortages in mathematics, physics, chemistry, and earth science in 1978 and greater shortages in all those fields by 1983.[18] An annual survey of state science supervisors between 1980 and 1982 found that they believe the shortage of science teachers to increase or stay about the same each year. By 1982, 42 out of 45 responding states reported a mathematics teacher shortage and 42 out of 47 responding states noted a physics teacher shortage. Science teacher shortages seem to be modest or nonexistent in biology and general science.[19] Another 1983 survey showed a science and/or mathematics teacher shortage in 38 states.[20]

United States Department of Education surveys show a drop of 64 percent and 33 percent in mathematics education and science education graduates, respectively, at the bachelor degree level in 1981, compared with a decade earlier. The average for all fields of education was a drop of 39 percent.[21] The general decrease reflects the impact of declining student enrollments in many states created by a drop in birth rates.

Much of the shortage has been met by assigning teachers with other specializations to mathematics and science classrooms on an emergency or provisional basis. A survey of 1979-80 bachelor degree recipients who were teaching in May 1981 found that 56 percent of those teaching science and mathematics were not certified or eligible for certification in the field in which they were currently teaching. This compares with 22 percent for all teachers and 26 percent for all specialty teachers.[22] A sample of 1,000 secondary school administrators surveyed by the National Science Teachers Association in December 1981 found that half the newly employed science and mathematics teachers were reported by administrators to be "unqualified" to teach science and mathematics.[23]

Although it would appear obvious that recent actions by states to raise graduation requirements in mathematics and science will increase enrollments and consequently create additional shortages of mathematics and science teachers, in reality such shortages may not occur. States are increasing the science and mathematics requirements. One 1983 analysis found that 11 states have increased graduation requirements in mathematics since 1980, while 11 others were seriously considering increased requirements. Three states had increased science requirements while 7 had increases under serious consideration.[24] The recent commission reports recommending stiffer graduation requirements are

likely to accelerate this trend. Yet, high school enrollments will still be declining as a result of lowered birth rates in the 1970's. Between 1985 and 1990, the drop will be from 13.6 million to 12.4 million, a decline of 8.8 percent or over 1.7 percent per year.[25] These declines will at least partially compensate for increases in demand for teachers due to increased graduation requirements. Even the increases due to stiffer graduation requirements may be illusory. One state official told us that their local school superintendents were informally polled about recently increased state requirements and none anticipated any impact because existing local requirements exceeded the new state minimum requirements in all cases. Future teacher shortages or surpluses in technical subjects are further influenced by the following factors: (1) number of persons newly certified to teach in mathematics and each science field each year; (2) turnover of teachers due to retirement, new employment outside of the classroom, death, and other reasons; (3) return of former teachers to the labor force; and (4) "market" solutions to shortages such as increased undergraduate enrollments in mathematics and science education programs as a result of the publicity over shortages of teachers in these fields. A study that systematically examines all or most of these components or factors in order to assess the current and future supply and demand for mathematics and science teachers has--to our knowledge and at the date of this writing--simply not been done.

The studies we have cited above have made various compromises in their research designs in order to attempt to measure the supply and demand in mathematics and science teaching. We found the resulting study designs and the data available from these studies to be seriously flawed. For example, both the survey of teacher placement officers and the survey of state science supervisors are based on simple opinion checklists. The respondents are asked to indicate for each field (38 fields for the former and 6 technical subjects for the latter) the shortage or surplus of teachers on five-point scales.[26]

There are sources of possible bias in data from such studies. At one level, the increased awareness of a shortage problem may increase the amount of reporting of shortage problems when no actual increase of the problem is occurring. At another level, the respondents providing the basic data and perhaps the groups sponsoring the studies cannot be said to be without self-interest. Findings suggesting that shortages are greater rather than smaller would appear to enhance the role of science supervisors and teacher placement officials. One national expert in the quantity of mathematics and science teachers told us that some state officials have admitted off-the-record that they have shortages only in some locations within the state rather than statewide shortages.

We conclude, therefore, that the data do not now exist to determine with confidence whether or not there is a net nationwide shortage of mathematics and physical science teachers.

Surely there are some local shortages. We did not search for state surveys so there may be well-documented shortages in individual states. Nationwide data showing that a high proportion of new mathematics and science teachers were not certified in their current teaching field certainly suggest a shortage situation. Yet other key questions--how poorly prepared are these teachers and do they subsequently obtain certification?--remain unanswered. Are we concluding that there is no teacher shortage in science and mathematics? Certainly not. But we do conclude that there exists no reliable statistic on the current or future national shortage of teachers in mathematics, physics, or other science fields.

Quality

Most of the concerns about the quality of mathematics and science teaching are inferential, based on surrogate measures of quality such as certification or on characteristics of teachers in all fields rather than technical teachers alone. The prominence of uncertified teachers among the new recruits to mathematics and science teaching as cited above raises questions about the quality of their preparation and their classroom effectiveness. Further, education generally has attracted for undergraduate majors those with low scores on standardized achievement tests. College bound seniors intending to study education ranked 26 out of 29 majors on the 1981 Scholastic Aptitude Test on both the mathematics and verbal subtests. Only home economics (27), ethnic studies (28), and trade and vocational (29) ranked lower. From 1973 to 1981, verbal scores for prospective education majors dropped 27 points while mathematics scores fell 31 points. Both declines exceeded the national average for all fields of 21 and 15 points, respectively. Scores of education majors on the Graduate Record Exam were substantially lower than scores of majors in 8 other professional fields in 1975-76.[27] These findings may or may not signal a further decline from the low achievement levels of education majors found in similar analyses during the 1950's. One study of 10,000 college graduates reported in 1954 that education ranked 17 among 20 fields of study.[28]

A followup study of the National Longitudinal Study of 1972 High School Seniors presents a disturbing portrayal of those who remain in teaching. Verbal and mathematics subtest scores in the Scholastic Aptitude Test were examined for those who 7 years later had graduated from college. The results were essentially identical for both subtests. The highest scoring group--averaging 496 on the verbal subtest--was the nonrecruits, those who did not major in education and never taught. Lower scoring and essentially tied were the "defectors" (averaging 462) and the "confirmed defectors" (averaging 460). The former were teachers who do not intend to teach at age 30. The latter were ex-teachers. At the bottom--averaging 432--were the "committed teachers," those who taught and intended to be teaching at age 30. The rankings are the same on the mathematical reasoning

subtest. Nonrecruits averaged 537, defectors and confirmed defectors 483, and committed teachers 470.[29] In short, not only are the academically less able attracted to teaching school but the least able are retained in the field.

One temptation is to raise standards for admission to undergraduate education programs at colleges and universities. States have been moving rapidly to require teacher testing for admission to teacher education programs or at some point in the certification process.[30] Yet in the National Longitudinal Study samples, excluding those in the bottom 20 percent in measured verbal ability (combining nonrecruits and recruits to teaching) would remove 30 percent of the teachers and 34 percent of the "committed teachers." In mathematical reasoning ability, the percentages are 30 and 29, respectively.[31] Excluding this bottom fifth of teachers from the field would raise the quality level--at least as measured by a standardized test--but would reduce the quantity of teachers available and thus create new shortages. Efforts could be undertaken to recruit students in the upper quarter of their high school class as mathematics and science teachers, but persons with this level of ability may simply not be interested in teaching careers.[32]

These findings raise the question of the relationship between a teacher's academic ability and teaching effectiveness. Do we need brighter teachers or are they inherently impatient, lacking in empathy, or likely to be bored by working with children?[33] We explore the relationship between teacher knowledge and teaching effectiveness as well as describe recent research on effective teacher classroom behavior in the next chapter.

WHAT REMEDIES HAVE BEEN PROPOSED FOR THESE PROBLEMS?

Observers frequently cite two major causes of the difficulty in attracting more and better people to teaching mathematics and science. One is the low level of teacher salaries. One study found that the 1981-82 average starting salary for bachelor degree teachers was $12,769.[34] A study of approximately 200 companies found that industry was offering those with a bachelor degree in mathematics or statistics an average starting salary of $18,600, or about $5,800 more than starting teachers. Salaries in chemistry ($19,536) and computer sciences ($20,364) were even higher.[35] It is not surprising that a survey of college graduates newly qualified to teach in May 1981 found that 27 percent of mathematics education graduates--nearly twice the average for all education fields--did not even apply for a teaching job.[36]

There are some efforts to remedy this salary disadvantage through bonuses for new teachers in mathematics and science and other shortage areas. Some school districts even offer higher salaries for teachers in shortage areas. Such remedies are un-

popular with teacher unions, which argue that all teachers should receive the same base pay. Local businesses may be asked to pay bonuses to teachers in some communities in order to avoid confrontations between the schools and unions on this issue. Given the magnitude of the $5,800-gap in starting salaries and the belief that many school districts and state and local governments are in a weak financial condition, it is not clear that meaningful improvements can be expected in the salaries of teachers in science, mathematics, or other fields. Low salaries may continue to be a barrier to reducing the mathematics and science teacher shortage.

A second major impediment to teacher recruitment concerns teacher morale problems. One component is the public's negative views of the public schools. The percentage of the public assigning "bad grades" (C through F) for the public schools increased from 32 percent in 1974 to 52 percent in 1983.[37] In 1983, a quarter of those polled cited discipline as the top problem facing schools, followed by drugs at 18 percent, poor curriculum and standards at 14 percent, and lack of proper financial support at 13 percent.[38] From the teacher's perspective, only 58 percent of public school teachers polled by the National Education Association say they would become teachers again if they could go back to their college days. Teachers reported satisfaction with support they received from their principals and with the personal fulfillment of teaching. The main drawbacks cited were the amount of clerical duties and the lack of clerical help.[39]

Ernest Boyer, President of the Carnegie Foundation for the Advancement of Teaching, says that the recent Carnegie study on the American high school depicts the "loneliness and powerlessness" of high school teachers. "The decline in the enthusiasm for teaching is rooted in the feeling that it's all been taken away--course outlines, textbooks, even the methods of supervision and discipline."[40] Teacher morale problems thus include both problems of job conditions within the schools and the low public perception of the schools and of teaching.

Improving teacher salaries and teacher morale could be expected to improve both the quantity and quality of mathematics and science teachers. These are probably relatively long-term goals. In the shorter run, the Congress is considering legislation to upgrade mathematics and science education. The House passed House of Representatives 1310, the Emergency Mathematics and Science Education and Jobs Act, on March 2, 1983. The Senate Committee on Labor and Human Resources reported another bill, Senate 1285, the Education for Economic Security Act, on May 16, 1983. As of this writing, the bill has not been debated by the Senate. The Senate bill authorizes $405 million in fiscal year 1984 compared with $425 million in the House bill or about $1,900 per existing secondary school science and mathematics teacher.[41]

Table 2

Mathematics and Science Teacher Quantity Remedies Included in Proposed Legislation

More new teachers for mathematics and science classrooms

1. Programs to retrain teachers and other appropriate school personnel for mathematics/science teaching.
2. Partnerships where staff from businesses serve as teachers, lecturers, consultants to schools.
3. Scholarships for preservice education for future mathematics and science teachers.
4. Program to increase the representation of typically underrepresented groups in mathematics and science teaching.
5. Development and dissemination of programs and materials for retraining teachers.

Morale improvements to retain existing mathematics and science teachers

1. Awards for teaching excellence.
2. Teacher service or employment in business firms under partnership programs.
3. Teacher incentive grants in which only graduates of training programs under this legislation can apply for grants of equipment and materials for their schools.

Evaluation of the above programs

SOURCE: H.R. 1310 and S. 1285.

Table 2 shows the major teacher quantity remedies supported under these two bills. The need for additional teachers would be addressed by a variety of programs, including programs to retrain teachers from other fields, partnership programs where staff from businesses teach in the schools, and scholarship programs at the undergraduate level. The proposed legislation also includes provisions such as awards for teaching excellence and summer jobs aimed at retaining existing mathematics and science teachers.

Table 3 shows the major teacher quality remedies that would receive federal support. A variety of teacher training programs for current and newly employed mathematics and science teachers are included. The purchase of mathematics and science instructional equipment and materials as well as the development and dissemination of materials and programs are proposed for support along with certain evaluation and research activities.

Table 3

Mathematics and Science Teacher Quality
Remedies Included in Proposed Legislation

Teacher training

1. Assistance in the form of scholarships and traineeships for current or new mathematics and science teachers.
2. Teacher institutes for mathematics and science teachers.
3. Inservice training for teachers and other appropriate school personnel.
4. Rural area inservice training and curriculum development.
5. Program to train teachers in programs operated by the private sector.

Equipment, materials, and programs

1. Purchase of mathematics and science instructional equipment and materials.
2. Modernization or improvement of instructional programs.
3. Development and dissemination of materials and programs for training.
4. Partnership programs for the sharing of equipment and facilities.

Evaluation and research

1. Evaluation of the above programs.
2. Research on effective methods of instruction, effective programs, curriculum development and materials, and teacher retention.

SOURCE: H.R. 1310 and S. 1285.

The tables show only part of the multiplicity of strategies in the bills. Assistance is provided through State Education Agencies (SEA's), local education agencies (LEA's), and universities as well as the various partnerships involving these institutions and science museums and private businesses. In many cases --teacher training is a good example--the activity is authorized under separate component programs providing funds to SEA's, universities, and the like.

In addition to remedies for both teacher quality and quantity, the legislation would support a variety of activities to improve school quality. Although school quality issues are outside the focus of this report, which is on remedies dealing with teachers and teaching materials and programs, we note for

completeness that the bills would support projects for gifted and talented students, computer learning and instruction, and foreign language instruction training and materials. The National Commission on Excellence in Education and other groups have recommended numerous school quality reforms. Many are now being adopted or considered at the state and local level without any prospects for federal funding. For example, steps to lengthen the school day and school year and proposals to require more mathematics and science courses for high school graduation may improve school quality by increasing the amount of learning time. Instituting a more demanding curriculum and tougher grading standards could be low cost locally initiated actions aimed at improving program quality. Some reformers call for sweeping long-term changes but even here some priorities such as teacher upgrading or reducing the teacher shortage seem needed.

SUMMARY

Part of the concern for mathematics and science education in the public schools seems powered by concerns over the position of the United States in international economic competition. We have seen that there are several educational priorities to improve American competitiveness. Some commentators recommend expanded and improved technical education while others do not. Those who place priority upon mathematics and science education are concerned over evidence of a shortage of teachers in the public schools.

We find the data documenting these shortages--mostly opinion surveys--to be very weak and believe teacher shortages to be basically undocumented today. Concerns over the quality of new mathematics and science teachers are largely inferential, based upon the prominence of uncertified teachers among the new recruits to mathematics and science teaching as well as the modest academic credentials of teachers generally, compared with other professions requiring college study. In the next chapter, we examine one remedy to teaching quality concerns, institutes to upgrade existing technical teachers.

NOTES

[1]New York Times, January 26, 1983.

[2]Task Force on Education for Economic Growth, Action for Excellence (Denver: Education Commission of the States, 1983), p. 14.

[3]Task Force, p. 14.

[4]Congressional Record, March 2, 1983, p. H705.

[5]Congressional Record, p. H705.

[6]Henry M. Levin and Russell W. Rumberger, "The Educational Implications of High Technology," project report 83-A4 to the National

Institute of Education, Stanford University, Palo Alto, Calif., 1983, p. 11.

[7]The National Commission on Excellence in Education, A Nation at Risk: The Imperative for Educational Reform (Washington, D.C.: U.S. Government Printing Office, 1983), p. 10.

[8]Levin and Rumberger, pp. 5 and 9.

[9]Jordan D. Lewis, "Technology, Enterprise, and American Economic Growth," Science, March 5, 1982, p. 1206.

[10]Lewis, p. 1206.

[11]Lewis, p. 1206.

[12]Lewis, p. 1208.

[13]Task Force, p. 16.

[14]Levin and Rumberger, p. 12.

[15]Task Force, p. 18.

[16]Task Force, p. 17.

[17]National Commission on Excellence in Education, p. 12.

[18]"Databank," Education Week, February 16, 1983.

[19]Trevor G. Howe and Jack A. Gerlovich, "National Study of the Estimated Supply and Demand of Secondary Science and Mathematics Teachers, 1980-1982," Ames, Iowa, Iowa State University, 1982, table 7 and pp. 18 and 23. Cover letters of request from the Council of State Science Supervisors and the authors were sent. We excluded Washington, D.C., American Samoa, and Puerto Rico. See also "Databank."

[20]Patricia Flakus-Mosqueda, Survey of States' Teacher Policies: Working Paper Number 2 (Denver: Education Governance Center, Education Commission of the States, October 1983), pp. 83-95.

[21]National Center for Education Statistics, The Condition of Education, 1983 Edition (Washington, D.C.: U.S. Department of Education, 1983), p. 188.

[22]National Center for Education Statistics, p. 206. These percentages are slightly inflated since they include a small percentage of "don't knows."

[23]James A. Shymansky and Bill G. Aldridge, "The Teacher Crisis in Secondary School Science and Mathematics," Educational Leadership, November 1982, pp. 61-62.