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ABSTRACT

To provide information to the Congress in its continuing debates over improving science and mathematics (S/M) education as well as to education policymakers, the General Accounting Office (GAO) synthesized past evaluation and research studies and used other methodologies to examine four issues: (1) the nature of the problem and its remedies; (2) prospects for upgrading existing S/M teachers; (3) prospects for reducing the S/M teacher shortage by retraining teachers from other subject areas; and (4) the current ability to evaluate the quantity and quality of S/M teaching. Observations on the implications of this work for S/M education legislation are included. GAO does not find evidence that training programs to upgrade existing S/M 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 science and mathematics classes seem to be one viable solution to technical teacher shortages. In addition, gaps in information available to policymakers are so severe that GAO could not determine if there are net nationwide shortages of S/M teachers and if the quality of technical teaching has declined in recent years. (JN)

REPORT BY THE U.S.

General Accounting Office

New Directions For Federal Programs To Aid Mathematics And Science Teaching

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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

GENERAL ACCOUNTING OFFICE
REPORT

NEW DIRECTIONS FOR FEDERAL
PROGRAMS TO AID MATHEMATICS
AND SCIENCE TEACHING

DIGEST

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)

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 1979 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)

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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 ' 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 unpopular 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.

[24] Sol H. Pelavin et al., Analysis of the National Availability of Mathematics and Science Teachers: Draft Report (Washington, D.C.: Pelavin Associates and Policy Studies Associates, 1983), pp. 20-22.

[25] Martin M. Frankel and Debra E. Gerald, Projections of Education Statistics to 1990-91, vol. 1, Analytical Report (Washington, D.C.: National Center for Education Statistics, U.S. Department of Education, 1982), p. 34.

[26] The teacher placement official checklist is sent to 67 placement officers who are asked to rate the supply and demand for teachers (on a scale of considerable shortage, slight shortage, balanced, slight surplus, considerable surplus) for each field. The survey of state science supervisors asks for a rating of the supply in the respondent's state for each technical field. Each state is rated by only one respondent and the state ratings are averaged to produce national supply estimates. An unbalanced rating scale is used: surplus, slight surplus, adequate, shortage, critical shortage. James N. Akin, "Teacher Supply/Demand 1982," Association for School, College and University Staffing, Madison, Wis., 1982; Howe and Gerlovich.

[27] Gary Sykes, "Teacher Preparation and the Teacher Workforce: Problems and Prospects for the 80s," American Education, 19 (March 1983), 23-24.

[28] D. Wolfle, America's Resources of Specialized Talent (New York: Harper and Brothers, 1954).

[29] Victor S. Vance and Phillip C. Schlechty, "The Distribution of Academic Ability in the Teaching Force: Policy Implications," Phi Delta Kappan, September 1982, pp. 22-24.

[30] C. Emily Feistritzer, The Condition of Teaching: A State by State Analysis (Princeton, N.J.: Carnegie Foundation for the Advancement of Teaching, 1983), pp. 92-98.

[31] Vance and Schlechty, tables 1 and 2. Committed teachers are the subgroup of teachers who were teaching in 1976-79 and intended to be teaching at age 30.

[32] Vance and Schlechty, pp. 25-27.

[33] Vance and Schlechty, p. 25.

[34] "Prices, Budgets, Salaries, and Income," NEA Research Memo, February 1983, p. 22. Also see Teacher Supply and Demand in Public Schools, 1981-82, NEA Research Memo, 1983, pp. 9 and 27.

[35] "Prices, Budgets, Salaries, and Income," p. 22.

[36] National Center for Education Statistics, pp. 190 and 231-32.

[37] George H. Gallup, "The 15th Annual Gallup Poll of the Public's Attitudes Toward The Public Schools," Phi Delta Kappan, September 1983, p. 35. Also see Gallup, "The 14th Annual Gallup Poll of the Public's Attitudes Toward The Public Schools," Phi Delta Kappan, September 1982, p. 39.

[38] Gallup, "The 15th Annual," p. 35.

[39] "Teachers Uncertain About Wisdom of Their Career Choice," Education Daily, July 7, 1983, pp. 3-4.

[40] "Carnegie Profile Outlines Teaching 'In Crisis,'" Higher Education Daily, August 24, 1983, p. 2.

[41] A. Stafford Metz and John P. Sietsma, "Teachers Employed in Public Schools 1979-80," Special Report (Washington, D.C.: National Center for Education Statistics, U.S. Department of Education, May 1982), p. 5.

CHAPTER 3

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

In the previous chapter, we noted that one of the major remedies for the perceived low quality of mathematics and science teaching is a variety of in-service and summer training programs for existing teachers. Fears that too often teachers began their careers with less academic ability than might have been desired lead directly to suggestions for subject matter training to upgrade existing teachers.

In this chapter, we explore one teacher quality improvement remedy--upgrading--in order to determine what the prospects are for improving the effectiveness of mathematics and science teaching through training to upgrade existing teachers. We begin with a review of the National Science Foundation teacher institute programs, which addressed very similar concerns from the mid-1950's to the mid-1970's. We examine the types of institutes and scope of the programs and review evaluation data on the participants and some of the effects of these programs. We review research findings on the relationship between the knowledge of teachers and the subsequent learning of their students. We explore some more recent approaches to improving student learning and present some concluding observations.

WHAT WAS THE EXTENT AND NATURE OF PARTICIPATION IN THE NSF INSTITUTE PROGRAM?

Interest in the NSF program of institutes for precollege science and mathematics teachers has been revived because the institutes have again been proposed to help upgrade our technical education capability. Although the current motivation is the improvement of our economic productivity and international competitiveness, there is no indication that the role of the institutes is conceived to be fundamentally different today than the program that began with a summer institute at the University of Washington in 1954.[1]

Background

The original goals of the NSF institutes were--

"(1) to increase the effectiveness of teachers by broadening and updating their scientific background;

(2) renew interest in an attitude of teachers toward science and their task as a factor in the motivation and encouragement of their students;

(3) improve communications, sympathy and understanding between groups (researchers versus teachers, for example)."[2]

Three types of institutes were developed: summer institutes, in-service institutes, and academic year institutes. Summer institutes, the first type funded, were patterned after industrial prototypes developed in the 1940's by General Electric, Westinghouse, and others.[3] Summer institutes, typically held at college campuses, featured small subsistence stipends for most of those teachers attending. Lasting from 6 to 8 weeks, summer institutes would aim to improve the mastery of subject matter in mathematics and a variety of science fields.[4] Table 4 shows that summer institutes were the largest of the institute programs, measured by number of grants, number of participants, or dollars. (Dollars in table 4 are unadjusted.)

The next largest in terms of number of grants or participants were the in-service institutes. Providing training on a part-time basis during the school year, the in-service institute

Table 4

NSF Institutes for Secondary School Teachers: Number of Grants, Number of Participants, Amount Obligated, and Cost per Participant, Cumulative for Fiscal Years 1954 through 1973: Total and by Type of Institute

	Number of grants (1)	%	Number of participants (2)	%	Amount obligated (3)	%	Cost per participant[a] (4)
Summer institutes	6,084	57	278,629	58	$330,705,337	64	$1,187
In-service institutes	3,817	36	180,053	38	47,630,290	9	265
Academic year institutes	767	7	21,453	4	135,717,737	26	6,326
Total	10,668	100	480,135	100	$514,053,364	99	$1,071

[a] Column 3 divided by column 2.

SOURCE: National Science Foundation, Precollege Science Curriculum Activities of the National Science Foundation: A Report of the Science Curriculum Review Team (Washington, D.C.: National Science Foundation, 1975), p. 25.

program paid for a teacher's tuition, local travel allowance, and textbook fees. Groups of teachers, typically 40 to 45 in number, would meet after school hours or on Saturdays.[5]

The academic year institute program consisted of full-time programs of study, often leading to a master's degree. The program objectives included updating subject matter knowledge, training in depth, and advanced specialized training.[6] Later, even the summer institutes were sometimes organized on a sequential basis for high school teachers to obtain advanced degrees. Academic year institutes were like sabbatical fellowships with specially designed curricula and some courses not normally offered by the university. Using table 4 to obtain crude cost per participant figures, note that academic year institutes cost $6,326 per participant. The cost may be attributable to stipends made available to provide partial salary recovery.[7]

At the same time, NSF began work to upgrade obsolete mathematics and science curricula. Over the years, an "alphabet curricula" ranging from School Mathematics Study Group (SMSG) mathematics to Biological Science Curriculum Study (BSCS) biology were developed. A separate program, the Cooperative College-School Science Program had been set up to provide collaborative programs between secondary schools and colleges for the improvement of school science instruction.[8] This program was used by 1964 to support close collaboration between college and secondary school officials in "the planning, adaptation, and introduction of the newly developed science curricula into one or more nearby school systems."[9] This was an early step by NSF into curriculum implementation activities.[10] As the curriculum materials became available, institutes were also utilized to help teachers learn the curricula. By 1965, about 20 percent of the summer institutes had a major orientation towards one of the revised curricula.[11] Subsequent to 1970, NSF phased out the discipline-oriented institutes and emphasized curriculum instruction for teachers and the implementation of curricula in specific schools or school districts.[12] By fiscal year 1974, the institutes had been replaced with implementation workshops.[13] The Office of Management and Budget apparently was opposing NSF programs it considered to be continuing federal aid and was more favorable toward problemsolving projects such as helping some region upgrade science education in its local schools.[14] The curricula activities had become a major dilemma for NSF. On the one hand, the slow rate of adoption of NSF-funded curricula by school districts created an incentive for NSF to assist the implementation effort. On the other hand, the charge that the federal government was influencing curriculum content stirred controversy in many quarters.[15]

A variety of causes led to the termination of the implementation workshops in 1975. First, the shortage of scientists had turned into a surplus.[16] Second, the director of NSF declared victory, stating that the institutes had achieved their maximum benefit.[17] Third, a major dispute had erupted over the cultural relativism portrayed in a social science curriculum, "Man--A Course of Study," funded by NSF. The dispute expanded into larger questions of NSF decisionmaking and marketing questions.[18] Fourth, the NSF precollege activities were a concern of its governing board, which was disturbed over growing problems of the limited funding available for university research.[19] Fifth, the opposition of the Office of Management and Budget to continuing aid programs such as the institutes was noted in the previous paragraph.

In fiscal year 1977, the Congress reinstated a small precollege teacher development program. This continuing program has been similar to the former in-service institute program, part-time and local in its orientation, with more input from the teachers and consequently more emphasis on classroom problems than under the institutes. NSF has funded no evaluations of this program.

There have been several other small NSF programs aimed at having impacts on mathematics and science education in elementary and secondary schools. An information dissemination for science education program aimed at disseminating information on curriculum and instructional materials and otherwise improving instruction was funded through fiscal year 1980. A development in science education program has funded the development and experimentation with ideas having the potential for improving science education. The Research in Science Education program is aimed at creating an organized body of knowledge on science education.

New programs totaling $15 million in fiscal year 1983 and $54.7 million in 1984 include a materials development for precollege science and mathematics program.[20] The research and development activities under this program are similar to those discussed above. A second new effort is the Presidential Awards for Teaching Excellence in Science and Mathematics program. In 1983, one science and one mathematics teacher from each state was invited to a ceremony in the District of Columbia. Under this program, each teacher received a $5,000 grant for use by his or her school in science and mathematics improvement. Another new program is the Honors Workshops for Teachers of Science and Mathematics, a highly selective search for outstanding teachers. The teachers will attend workshops for about 4 weeks and may introduce innovations from the workshops into their schools upon their return.

In some respects, the current goals seem closer to the earlier than to the later NSF institute programs. These last institutes marked a time of reduced concern over the quality of teachers and a growing internal problem over increasing the adoption or utilization of the NSF-funded curricula.

Evaluation criteria

We first explore the most elementary measure of the institute program's effectiveness, the extent of institute participation. After reviewing the extent of participation we examine the characteristics of participants. We then turn to another measure of impact, the effect of institute attendance upon the subsequent science or mathematics achievement of the attending teachers' students. (Other possible evaluation criteria are discussed in appendix I.)

Extent of participation

As the figures in table 4 may have suggested, participation in the NSF institute programs was widespread. A study of mathematics and science teachers reported in 1962 that 36 percent of the public senior high school teachers and 24 percent of the junior high school teachers had attended NSF institutes. While limited to the prior 5 years, in effect this is a study of participation rates early in the NSF program.[21]

In a 1971 survey of 2,489 public secondary schools, 51 percent of secondary school science teachers reported having attended one or more NSF summer institutes. Many people attended more than one institute; 34 percent of the science teachers had attended two or more NSF summer institutes. Furthermore, 28 percent of the science teachers reported having attended NSF in-service training and 9 percent attended NSF academic year institutes.[22] A weakness of this survey, however, was its low rate of usable responses--only about 39 percent for teachers.

A 1977 national survey of teachers at all grade levels asked teachers about their attendance at NSF institutes. As table 5 shows, at grades 10-12, 52 percent of the science teachers and 38 percent of the mathematics teachers reported attending one or more institutes. At grades 7-9, the attendance estimates drop to 33 percent of science teachers and 27 percent of mathematics teachers. The figures are lower in the elementary grades where teachers usually are not specialists but teach all academic subjects. The teacher response rate of 76 percent in this survey apparently is the response from participating schools; thus a participation rate based on the total sample of schools, which was requested to participate, would be lower.[23]

Using questionnaires to ask teachers to recall past institute attendance as well as sponsorship of these institutes is likely to produce substantial measurement error. Major differences in questions asked, year of administration, and survey design also make it difficult to compare these surveys. However, all three surveys suggest that participation in the NSF institute programs was fairly extensive; about half of the senior high school mathematics and science teachers participated

Table 5

Percent of Teachers Reporting Attending One or More NSF Institutes, by Grade Level and Subject Area, 1977

Grade and subject	Percent of teachers attending[a]
Grades 10-12	
Science	52
Mathematics	38
Grades 7-9	
Science	33
Mathematics	27
Grades 4-6	
Science	13
Mathematics	6
Grades K-3	
Science	2
Mathematics	5

[a] Allocates the missing or inconsistent responses proportionately to the attending and nonattending categories.

SOURCE: Iris R. Weiss, Report of the 1977 National Survey of Science, Mathematics and Social Studies Education (Research Triangle Park, N.C.: Research Triangle Institute, 1978), p. 69.

in the institutes. Clearly the elementary school teacher participation was lower, estimated at 14 percent in another study.[24] This is consistent with our knowledge of NSF priorities. In the absence of departmentalization in the typical elementary school, NSF emphasized training key teachers or supervisors who might in turn improve the mathematics and science instruction in their home schools. This attempt at having an impact on the large number of elementary schools and elementary school teachers was not considered successful. Elementary school teacher summer and in-service programs were terminated in fiscal year 1966.[25]

Characteristic of participants

Who--in the NSF institute experience--applied and subsequently was admitted to and attended NSF institutes? The process was similar to standard college admissions. Teachers applied individually and were accepted or rejected by institute personnel. A common application form was used but NSF did not specify to institute directors how they were to use the information provided. The institutes in turn had to specify in their proposals how they would select participants, but once the applications were sent in there were no selection rules from NSF. The NSF position was simply that the major criterion should be the ability to benefit from an institute. Several studies are available, which suggest the characteristics of those who participated.

A 1962 study describes a sample of 1,845 target teachers--teachers who taught mathematics or science at least 40 percent of the time and were from 25 to 55 years old--in 427 participating secondary schools. Those teachers reporting that they applied to NSF summer, in-service, and academic year institutes, as compared with nonapplicants

--had more college credit hours in mathematics or science at both the undergraduate and graduate levels;

--reported more job satisfaction;

--engaged in more professional activities, including reading journals and belonging to and holding office in professional societies.[26]

The study characterized nonapplicants as having generally low levels of self-improvement motivation in their work. They recognized that they needed better subject matter preparation but did not apply to attend institutes. Although they reported keeping up through reading, in fact they read fewer journals than applicants. The nonapplicants were overrepresented in rural areas and small schools having less extensive course offerings. These teachers thus were much more likely to teach in at least one other subject matter field, which presumably decreased their identification with mathematics or science. We caution the reader that we were not able to verify that the findings reported here were consistent with the data collected due to the limitations in the statistical tables provided.

This study was disturbing in the sense that it suggested that the large number of nonparticipants in institutes could benefit from additional preparation but seemed unlikely to seek it. We discuss training for less qualified teachers at the end of this chapter and in chapter 6.

A 1971 survey identified teacher and school characteristics, which were associated with participation in an institute. Regression analyses aimed at relating institute attendance with teacher and school characteristics yielded few notable relationships. In analyses of the total sample of about 2,193 teachers, only the teachers' number of semester hours in college science courses was significantly related to attendance at a summer institute. No teacher or school characteristic was found to be significantly related to the amount of participation in in-service institutes. Attendance in any NSF institute (as opposed to the analyses for different types of institutes individually) was related to the number of semester hours in college science and years of secondary school science teaching experience.[27] This analysis--unless the choice of dependent variables was unfortunate--suggests that there was little to differentiate those who attended few or many NSF institutes.

Several studies comparing those accepted and rejected for institute attendance have utilized data from the standard NSF institute application form. Table 6 provides data from a synthesis paper comparing summer institute selection studies in

Table 6

Characteristics of Teachers Accepted and Rejected for NSF Summer Institutes, by Year

	1957		1960		1964	
	Accepted	Rejected	Accepted	Rejected	Accepted	Rejected
Mean number of undergraduate semester hours in science	13.2	11.6	9.4	8.9	8.8	8.2
Mean number of graduate semester hours in science	1.6	1.0	1.5	1.5	1.6	1.1
Mean undergraduate grade point average in mathematics courses	2.9	2.7	2.7	2.6	2.6	2.4
Percentage of undergraduate science or mathematics majors	64.9	56.9	70.3	64.0	47.3	42.6
Mean number of years teaching experience for selected subjects						
Mathematics			5.1	5.3	4.1	3.8
Physics			2.2	2.0	1.2	0.9
Chemistry			2.6	2.2	1.6	1.2
Earth science			0.2	0.3	0.4	0.4

SOURCE: Adapted from Raymond M. Berger and Frances R. Berger, A Study of the Attributes of Applicants to National Science Foundation Summer Institutes in 1964 (Los Angeles: Psychometrics Consultants, 1965), pp. 7-31.

1957, 1960, and 1964. Some trends (not all of which are statistically significant) are that high school teachers selected had

--more semester hours in science than those rejected;

--more graduate semester hours in science (except in 1960 when there was no difference);

--slightly higher undergraduate grade point averages;

--greater likelihood of majoring in science or mathematics at the undergraduate level;[28]

--more years of science and mathematics teaching experience (except mathematics in 1960 and earth science).

In short, those with stronger academic credentials and more background in science and mathematics had higher probabilities of selection. There was some evidence of more memberships in professional organizations among those accepted.[29]

Table 6 data also suggest that by 1964 the qualifications of institute participants declined somewhat. Those accepted had 8.8 semester hours of undergraduate science compared with 9.4 in 1960 and 13.2 in 1957. A smaller percentage of the 1964 acceptees had been undergraduate science or mathematics majors than in the prior years. However, those selected continued to have somewhat stronger academic preparation than those rejected. Table 6 also shows that by 1964 those accepted for institute attendance had an average of less than 2 years experience teaching physics or chemistry (and earth science teachers had even less experience). There was some concern in NSF that the availability of institutes almost upon graduation from college might be undercutting the quality of teacher preparation programs. These statistics on science coursework and teaching experience support the 1970 NSF position we cited earlier--that the institutes had achieved one of their goals.

In summary, in this review of completed studies we have found some common factors. Participants had more undergraduate college science in all studies. Participants had more years secondary school science teaching experience than nonparticipants except for the 1962 study. Some "professionalism" findings were found in the 1962 and 1964 studies.

The institute program practiced a degree of academic selection or creaming. While the academic differences between the average participant and nonparticipant were apparently modest, we found them consistently. Since the institute programs were run by colleges and universities, it is not surprising that they operated on essentially a graduate school model of selecting the best academically qualified applicants. It seems unlikely that NSF resisted this practice. The academic-university orientation of NSF with its continued reluctance to conduct activities in precollege education has been cited widely.[30]

In conclusion, this subsection has shown that participation in the NSF institute programs was widespread. Participants had somewhat stronger academic qualifications--and possibly greater professionalism--than nonparticipants. We saw some evidence that over time the institutes remained selective but lowered requirements below those of earlier years. The question of how to attract and subsequently upgrade the nonapplicant teachers in programs such as these remains a troubling issue.

HOW EFFECTIVE WERE THE NSF INSTITUTES IN IMPROVING STUDENT ACHIEVEMENT?

We examine the impact of teachers' attendance at NSF institutes upon the subsequent achievement of their students in mathematics or science. In appendix I, we cite the other major outcomes of institute attendance that have been studied and the advantage of student achievement over the alternative outcomes. A major value of student achievement is that it represents the most fundamental goal of our educational system and, directly or indirectly, of most education programs at the precollege level. In addition, student achievement was a central concern of education commission reports that were published in 1983. The disadvantages of student achievement measures are technical considerations, which we cite in appendix I.

Applying our criteria for consideration and selection of studies (see appendix I), we found only one qualifying study of the impact of NSF institute attendance upon student achievement. However, it included four samples so it is really one report on four studies.

This effort--reported by Victor Willson and Antoine Garibaldi in 1976--examined the achievement of students whose teachers had participated in NSF institutes compared with the achievement of students whose teachers had not participated.[31] Principals of sampled schools randomly selected one science or mathematics teacher who in turn was asked to complete a questionnaire, take the applicable National Teacher Examination, and select one class at random for testing. Science students took the Test of Achievement in Science (consisting of 40 items selected from the National Assessment of Educational Progress) while mathematics students took the Mathematics Achievement Test (composed of 40 items from the National Longitudinal Study of Mathematical Abilities). Two forms were developed for each, one for 8th and one for 11th graders. A total of 346 teachers and classes participated in science and 211 in mathematics. Science classes were from schools sampled in Wyoming, South Dakota, and Mississippi regions while mathematics classes were in California and Indiana regions.

The results, which are discussed in more detail in appendix II, show that NSF institute participation was a statistically significant factor in high school science and mathematics achievement. The statistical significance levels were .06 and .02, respectively. However, institute participation was not significant for 8th-grade student achievement in either science or mathematics.

The results of four samples are not enough to conclude that NSF high school teacher institutes are effective and that junior high school teacher institutes are not.[32] We searched, therefore, for related evidence. Our search focused on the fact that subject matter training was a major element of the NSF institutes.[33] Does more general research on the relationship between teachers' knowledge and the knowledge of their students make a plausible case for expecting that the NSF institutes would help improve student achievement?

ARE MORE KNOWLEDGEABLE TEACHERS MORE EFFECTIVE TEACHERS?

What makes an effective teacher? If a teacher's primary function is to transmit knowledge, it would seem that the amount of knowledge the teacher has in the subject or more globally would be critical. Yet most of us have endured studying under brilliant teachers who were inept communicators. A teacher should also transmit some of the fascination with his or her subject to help motivate learning. Personality and pedagogical technique are other factors in the complex determination of effective teaching.

A 1963 review of studies on the relationship between teachers' intelligence and effectiveness showed little evidence of an association in the then-current literature.[34] The influential Coleman report concluded in 1966 that teachers' vocabulary test scores were associated with student verbal achievement for all minorities but no teacher or other school factors accounted for much variation in student achievement. The analysis found that "schools bring little influence to bear on a child's achievement that is independent of his background and general social context."[35]

In 1969, Arthur Rothman and colleagues published results of three studies of the relationship between teachers' tested knowledge of physics and their students' subsequent learning in physics. The three studies showed little relationship: one found three out of four correlations to be small but positive, one showed no overall relation between a large set of teacher and student variables, which led the investigators to reject examination of individual bivariate relationships, and one produced a small negative relationship between teacher achievement and student learning.[36]

A 1972 report by Edward Begle found in a study of 308 algebra teachers that teacher understanding of basic algebra had a significant positive correlation with student achievement in the understanding of 9th-grade algebra. However, Begle concluded that "while this correlation is statistically significant, it is so small as to be educationally insignificant."[37] In three other teacher-student knowledge correlations, there were no significant relationships.

In 1975, Frances Lawrenz reported from a study of 236 secondary school science teachers that teacher knowledge of the processes of science was positively related to student achievement but teacher subject matter knowledge as measured by the National Teacher Examination was negatively related to student achievement. Willson and Garibaldi reported the absence of relationships between teachers' science (or mathematics) ability and their students' achievement, as we note in the detailed discussion of that research in appendix II.[38]

Finally, Theodore Eisenberg replicated the Begle study to determine if the NSF institute participant volunteers Begle used may have unduly limited the variation in teacher knowledge. In his study of 28 Columbus, Ohio, junior high school teachers, Eisenberg reported in 1977 that he found nonsignificant correlations between residual teacher effects on student achievement (in algebraic concepts and algebraic skills) and teacher knowledge. The small sample size is a particularly serious weakness of this study in that it makes it difficult to produce significant correlations. Eisenberg reported that six other studies (not included here) were also in accord with Begle's findings.[39]

As a group, these studies fail to show any relationship between teacher knowledge and the knowledge gain of their students. Several of the studies are small and subject to methodological criticisms such as having a possibly biased group of participating teachers. However, another recent synthesis included dissertations and also found no consistent relationship between the knowledge of teachers and their students' achievement, suggesting that the exclusion of dissertations has not biased our findings.[40] Furthermore, this finding is consistent with the direction of ~~school research in the last decade.~~ As Purkey and Smith argued in a recent review article,

> "the general finding [is] that easily measurable differences among schools (class size variation from 20 to 30 pupils, existing differences in teacher preservice training, teacher experience and salaries . . .) have little consistent relationship to student achievement."[41]

Teacher knowledge seems to be one such variable that "can be measured and, in theory, changed relatively easily" through spending more to hire more knowledgeable teachers.[42] More recent studies have looked at different variables and not the teacher knowledge and related variables examined here.[43]

We cannot say that there is no link between teachers' knowledge and their students' learning with the confidence a researcher can have in saying there is no link between treating with Laetrile and curing cancer. However, research to date clearly has failed to show a straightforward relationship between teachers' knowledge and the subsequent learning by their students in mathematics and science, at least for teachers in classrooms in the early 1970's. This finding challenges a common assumption--the belief that the more a teacher knows about the subject being taught, the better the teaching that will be done and the more the student will learn about the subject in question.

It may be that there is evidence of favorable effects of higher levels of teacher knowledge on encouraging future careers in science and mathematics or some of the other outcomes we cite in appendix I. We have not reviewed this literature. Regarding the impact of teachers' knowledge on the important outcome of student achievement, we find no consistent relationship. We discuss some of the implications of this research for teachers in classrooms today at the end of this chapter.

WHAT DOES RECENT CLASSROOM RESEARCH TELL US ABOUT HOW TO IMPROVE STUDENT ACHIEVEMENT?

We have examined evaluations on the effectiveness of NSF institutes in improving student achievement and found only one study of sufficient quality. Since many of the NSF institutes focused on upgrading teachers' discipline or content knowledge, we then turned to more general research on the relationship between teachers' knowledge and the achievement of their students. The results of this latter inquiry failed to suggest benefits in upgrading teacher knowledge. We now turn to more recent approaches of attempts to improve teaching effectiveness through understanding and changing the classroom behavior of teachers. Rather than trying to increase teachers' knowledge of science or mathematics, this approach has the goal of improving how the teacher manages learning in the classroom.

Researchers in the 1970's identified teachers who were effective in increasing student achievement, observed them, as well as less effective teachers, and devised objective ways to classify and count specific teacher behaviors. It was then possible to study a cross-section of teachers and correlate objectively measured teacher classroom behavior with the amount of student learning. This is called "process-product" research because it relates the classroom processes to the outcome or product produced. The result of this research is lists of desirable behaviors, which turn out to include both classroom management skills and instructional strategies. Effective teachers are more likely than less effective teachers to

--provide and enforce clear and consistent rules of conduct;

--instruct and drill students in well thought out procedures for classroom behavior;

--respond more promptly to incipient misbehavior;

--maintain well-paced momentum in instruction;

--assign independent work, which will provide students with high (90-100 percent) levels of success;

--interact frequently with students providing prompt and frequent academic feedback to students by correcting papers, answering questions.[44]

How confident can we be in this list? We found no synthesis or assessment of the technical quality of this research and such an undertaking was beyond the scope of this report. The substantial number of publications in this area is somewhat offset by the fact that it represents a prolific output by a relatively small group of researchers. While classroom research may "still be in its infancy" as one of its leading members has written, it is encouraging that there is some consistency in the findings in the sense of pointing toward more active and organized teaching.[45] The research has a major weakness for the purposes of this report in that it is limited to the elementary grades while our analysis focuses on secondary schooling.

The process-product researchers have extended their research to develop training or instructional packages with the goal of training teachers to utilize those techniques, which their research has found to be effective. The researchers have then studied the training programs with two objectives. First, they have sought to determine the extent to which teachers implemented the changes recommended by the training. Second, they studied the success in classrooms where teachers had implemented the training in terms of improved student achievement. Put another way, they sought to determine if classroom management skills could be taught and if the success of teachers who utilized these methods naturally could be replicated. The results were encouraging in studies of 4th-grade mathematics in Oklahoma, 1st-grade reading in Texas, and 3rd-grade reading in California.[46] The fact that training programs were relatively short and required few materials is encouraging. Programs we identified ranged from two sessions to seven workshops.[47]

We find the work of the process-product researchers encouraging but not too useful for our purposes. The extension of this approach to exploration of effective teaching in secondary school mathematics and science classes could be a valuable contribution.

We end this section on process-product research by noting that other unrelated research, while beyond the scope of this report, may be of interest to some readers. One set of research concerns the literature on the nature of student understanding of science and mathematics concepts.[48] There is also an emerging literature on the use of computers to teach science and mathematics concepts through simulation.[49]

CONCLUSIONS

This chapter raises questions about approaches that have substantial teacher training components. Such programs are a prominent part of proposed federal legislation. Our analysis suggests that programs geared at upgrading existing mathematics and science teachers may not produce results in terms of improved student achievement.

We reviewed NSF institute participation data and found that this earlier program to increase teacher quality attracted roughly half of the senior high school mathematics and science teachers who were in the classrooms during the 1960's. Many teachers took extensive coursework under the Academic Year Institutes and later even obtained master's degrees under sequential Summer Institute programs. The participating half of the teaching force was somewhat more academically qualified than those not applying or not accepted. While the qualifications of participating teachers declined somewhat over time, the qualifications of applicants in general apparently declined as well, leaving a modest gap between those accepted and rejected. How to reach the nonparticipating teacher was never resolved under the NSF program. Perhaps the closer ties between universities and school districts under the proposed legislation would give school districts more leverage to obtain broader teacher participation. Under the NSF institute program, teachers applied at their own initiative.

We examined the effectiveness of NSF institutes in increasing the science and mathematics knowledge of students of the participating teachers but found only one study that met our minimum criteria. It found mixed results, with evidence of effectiveness of the institutes (statistically significant differences) at the senior high school but not the junior high school level.

We then searched for related evidence, focusing on the fact that subject matter training was a major element of the NSF institutes. We looked at the general research on the relationship between teachers' knowledge and the knowledge of their students as a way of further assessing the effectiveness of the strategy of upgrading teacher subject matter knowledge. The studies of secondary school science and mathematics learning in the 1960's and 1970's failed to show any straightforward relationship between teachers' knowledge and subsequent student learning.

We then turned to more recent approaches to increasing teacher effectiveness--the process-product research. This effort focuses on classroom management rather than on teacher knowledge, and it is aimed at identifying objectively the components of effective teaching, training teachers to adopt those components in their own classrooms, and attempting to replicate the effectiveness results for the trained teachers' classes. The results of this emerging research area are promising, but process-product research has not yet been attempted at the secondary school level.

This review of teacher quality remedies is not encouraging. Perhaps if we had included an examination of school quality improvement remedies cited in chapter 2 or school management approaches, we would have found different results.

There must be some limits on the lack of relationship between teachers' knowledge and subsequent learning by their students. Someone completely ignorant of calculus presumably could not teach it. The findings we reported were based on the range of knowledge of actual teachers in classrooms, which presumably filtered out those with very little knowledge of the subject. Perhaps the recent appearance of significant numbers and percentages of uncertified new mathematics and science teachers in the schools may have significantly lowered the average knowledge level and could therefore lead to different findings than those reported here. From a policy perspective, this may suggest a training approach of targeting training on the least qualified mathematics and science teachers. This approach in some ways is the opposite to the NSF institute strategy, but it seems to be called for in view of the apparent needs combined with the unlikely effectiveness of training for other groups of teachers.

This examination of effective approaches to increasing teacher quality in mathematics and science education has been hindered by the shortage of appropriate evaluation and research studies. We return to this matter in chapter 5 where we outline some possible approaches to evaluation under new proposed legislation. Now we turn to the issue of improving the quantity of science and mathematics teachers through retraining programs.

NOTES

[1] Milton Lomask, A Minor Miracle: An Informal History of the National Science Foundation (Washington, D.C.: National Science Foundation, 1976), p. 123.

[2] National Science Foundation, Precollege Science Curriculum Activities of the National Science Foundation: A Report of the Science Curriculum Review Team (Washington, D.C.: National Science Foundation, 1975), p. 24.

[3] Hillier Krieghbaum and Hugh Rawson, An Investment in Knowledge (New York: New York University Press, 1969), pp. 65-82.

[4] Langdon Crane, The National Science Foundation and Pre-College Science Education: 1950-1975 (Washington, D.C.: Congressional Research Service, 1975), pp. 3 and 88. Institutes were often administered by the subject matter department of the university but some project directors were from schools of education.

[5] National Science Foundation, p. 27. See also Crane, pp. 75 and 88.

[6] National Science Foundation, p. 27.

[7] Crane, p. 3.

[8] National Science Foundation, 12th Annual Report of the National Science Foundation (Washington, D.C.: 1963), p. 85, quoted in Crane, p. 82.

[9] The 13th annual NSF report, quoted in Crane, p. 94.

[10] Crane, p. 94.

[11] National Science Foundation, Precollege, p. 27.

[12] Crane, p. 9.

[13] "Report to the Planning and Policy Committee from the Subcommittee on Science and Engineering Education," National Science Board, Washington, D.C., March 19, 1982, appendix A, p. 9.

[14] Crane, pp. 121-122 and 154.

[15] Crane, p. 10.

[16] Wayne W. Welch, "Twenty Years of Science Curriculum Development: A Look Back," in David Berliner (ed.), Review of Research in Education, 1979 (Washington, D.C.: American Educational Research Association, 1979), p. 287. Also see Science Indicators, 1972 (Washington, D.C.: National Science Board, National Science Foundation, 1973), p. 59. Unemployment of scientists accelerated from 1969, reaching 2.6 percent by early 1971. The unemployment rate for scientists and engineers (and for all professional workers) declined in 1972. The report concludes that "employment prospects for new graduates were reported as better in 1972, although still not as good as those in the mid-1960's."

[17] Crane, pp. 145-46. Dr. William McElroy, Director of NSF, is quoted from hearings as testifying "Up to now we have put roughly $460 million into the summer institutes for high school teachers and we think we have reached the maximum benefit from this approach." McElroy testified that other programs dealing

with curricula were needed. He continued, "Until recently it has been the teacher on his own, going to summer institutes, with no real input back at his institution except possibly in his own classroom. We need to get the curriculums reformed throughout the system internally, so teachers identified by the principals will come back from training and become the leaders for curriculum reform in their own systems. . . ." In response to a question from a congressperson expressing concern over the size of cutbacks being proposed, Dr. McElroy commented: "The major cutback is in summer institutes for high school teachers . . . [but] 40 percent of our high school teachers have now participated in one or more of these [institutes]. . . . Unfortunately, we don't . . . know . . . how much further we can really go in reaching the football coach who is assigned to teach biology at the high school level."

[18] Crane, pp. 181-82 and 205-06.

[19] Crane, p. 9.

[20] These programs were initiated by NSF and were authorized through report language. The initial NSF plan was not approved by the Senate but the second plan was approved.

[21] David B. Orr, *A Study of Non-Applicants and Other Segments of the Secondary School Science and Mathematics Teacher Population: Final Report* (Washington, D.C.: American Institutes for Research in the Behavioral Sciences, 1962), p. II-9. Derived from the weighted N columns. Also see David B. Orr and Albert T. Young, Jr., "Who Attends NSF Institutes?" *The Science Teacher*, 30 (November 1963), 40.

[22] Fred R. Schlessinger et al., *A Survey of Science Teaching in Public Schools of the United States (1971)*, vol. 1, *Secondary Schools* (Columbus, Ohio: ERIC Information Analysis Center for Science, Mathematics and Environmental Education, 1973), pp. 98-100 and 7-8. The survey includes teachers in grades 7-12. The original sample was 6,298 schools, but the actual sample of usable principals' questionnaires was only 2,48[illegible] The item reported here is based on 2,471 principals' responses. The low response rate means that the possibility cannot be ruled out that participants were more likely to respond than nonparticipants, inflating the estimates of institute attendance. In addition, the question on which this analysis is based may have a response bias leading to overestimates of institute attendance. Teachers were asked to circle the year of each NSF institute attended. Responses range from 1960 to 1970 for each of four types of NSF institutes plus two rows for teachers to fill in other sponsored institutes. Teachers might have felt it was socially desirable to circle at least one of these 66 entries.

[23] Iris R. Weiss, *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education* (Research Triangle Park, N.C.: Research Triangle Institute, 1978), pp. 9-10 and 15-16.

[24] Robert L. Steiner et al., Survey of Science Education in Public Schools of the United States (1971), vol. 4, Elementary Schools (Columbus, Ohio: ERIC Information Analysis Center for Science, Mathematics and Environmental Education, 1974), cited in Stanley L. Helgeson et al., The Status of Pre-College Science, Mathematics, and Social Science Education: 1955-1975, vol. 1, Science Education, (Columbus, Ohio: Center for Science and Mathematics Education, 1977), pp. 177 and 240.

[25] National Science Foundation, Precollege, p. 27.

[26] Orr and Young, pp. 39-40. Also see Orr.

[27] Arthur L. White et al., A Survey of Science Teaching in Public Schools of the United States (1971), vol. 2, Secondary Schools (Columbus, Ohio: ERIC Information Analysis Center for Science, Mathematics, and Environmental Education, 1974), pp. 9-11 and 48-61. The total variation explained by the model was only 14 percent, making it a weak model of the variation in the data. Even these few statistically significant findings may not be educationally meaningful.

[28] Note that the figures in table 6 apply only to majors in science or mathematics. Other majors and combinations of majors (such as science and education) are not included here. Thus, this entry in table 6 should not be used to show level of preparation but to show differences between those accepted and rejected for institutes.

[29] Raymond M. Berger and Frances R. Berger, A Study of the Attributes of Applicants to National Science Foundation Summer Institutes in 1964 (Los Angeles: Psychometrics Consultants, 1965), pp. 7-31. The 1957 study was conducted by the Corporation for Economic and Industrial Research while the 1960 study was done by Science Research Associates. The sample sizes of acceptees are 5,154 in 1957, 2,805 in 1960, and 3,000 in 1964. There were rejectee samples of 3,912 in 1957, 2,787 in 1960, and 3,000 in 1964.

[30] Krieghbaum and Rawson, pp. 97 and 196-99. The "limitation clause" was included in numerous appropriation bills enacted by the Congress in order to ensure that funds for training high school science and mathematics teachers would not be reprogrammed by NSF for other uses.

[31] Victor L. Willson and Antoine M. Garibaldi, "The Association Between Teacher Participation in NSF Institutes and Student Achievement," Journal of Research in Science Teaching, 13:5 (1976), 431-39, and "The Effect of Teacher Participation in NSF Institutes Upon Student Achievement," research paper 10 revised, University of Minnesota, Minneapolis, September 30, 1974.

[32] We cite for the interested reader the results of a quantitative synthesis of research dealing with the effects of new science

curricula on student performance. This paper is germane here in the sense that studies included were coded regarding whether or not in-service teacher training was provided. Results show that "student overall performance was more positively enhanced by teachers who had received no special inservice education." (p. 399) The conclusion of this study is very consistent with the results of our analysis although we were not concerned with training specifically related to new science curricula. This study does not meet our selection criteria but we include it here at the independent suggestion of two reviewers of a prior draft of this report. Despite its methodological limitations, the study has the value of including a large sample of 105 studies, about 30 percent of which include information regarding in-service teacher training. James A. Shymansky et al., "The Effects of New Science Curricula on Student Performance," Journal of Research in Science Teaching, 20:5 (1983), 387-404.

[33] Krieghbaum and Rawson, p. 333.

[34] J.W. Getzels and P.W. Jackson, "The Teacher's Personality and Characteristics," in N. L. Gage (ed.), Handbook of Research on Teaching (Chicago: Rand McNally, 1963), pp. 506-82.

[35] James S. Coleman et al., Equality of Educational Opportunity (Washington, D.C.: U.S. Department of Health, Education, and Welfare, 1966), p. 325.

[36] Arthur I. Rothman, "Teacher Characteristics and Student Learning," Journal of Research in Science Teaching, 6 (1969), 340-48. Only one of these correlations is statistically significant. Arthur I. Rothman et al., "Physics Teacher Characteristics and Student Learning," Journal of Research in Science Teaching, 6 (1969), 59-63; Herbert J. Walberg and Arthur I. Rothman, "Teacher Achievement and Student Learning," Science Education, 53 (April 1969), 253-57.

[37] Edward G. Begle, Teacher Knowledge and Student Achievement in Algebra (Palo Alto, Calif.: School Mathematics Study Group, 1972), p. 8.

[38] Frances Lawrenz, "The Relationship Between Science Teacher Characteristics and Student Achievement and Attitude," Journal of Research in Science Teaching, 12:4 (1975), 433-37; Willson and Garibaldi, p. 435.

[39] Theodore A. Eisenberg, "Begle Revisited: Teacher Knowledge and Student Achievement in Algebra," Journal for Research in Mathematics Education, May 1977, pp. 216-22.

40Colin J. Byrne, "Teacher Knowledge and Teacher Effectiveness: A Literature Review, Theoretical Analysis and Discussion of Research Strategy," paper presented to the 14th Annual Convocation of the Northeastern Educational Research Association, Ellenville, N.Y., October 26-28, 1983, pp. 12-13, and 40-42.

[41] Stewart C. Purkey and Marshall S. Smith, "Effective Schools: A Review," The Elementary School Journal, 83:4 (1983), 428.

[42] Purkey and Smith, p. 427.

[43] Purkey and Smith, p. 428.

[44] Edmund T. Emmer, Carolyn M. Evertson, and Linda M. Anderson, "Effective Classroom Management at the Beginning of the School Year," The Elementary School Journal, 80 (May 1980), 225-26; Edmund T. Emmer and Carolyn M. Evertson, "Synthesis of Research on Classroom Management," Educational Leadership, January 1981, p. 345; Jere E. Brophy, "Classroom Organization and Management," The Elementary School Journal, 83 (March 1983), 267, and "Teacher Behavior and Its Effects," Journal of Educational Psychology, 71:6 (1979), 736; Jane Stallings, "Classroom Research, Implications for Mathematics and Science Education," paper presented to the Biological Science Curriculum Study Conference, Boulder, Colo., November 7, 1980, p. 8; Charles W. Fisher et al., "Teaching Behaviors, Academic Learning Time, and Student Achievement: An Overview," in Carolyn Denham and Ann Lieberman (eds.), Time to Learn (Washington, D.C.: National Institute of Education, May 1980), p. 20.

[45] Brophy, 1979, p. 738.

[46] Thomas L. Good and Douglas Grouws, "The Missouri Mathematics Effectiveness Project: An Experimental Study in Fourth Grade Classrooms," Journal of Educational Psychology, 71:3 (1979), 359-60; Linda M. Anderson, Carolyn M. Evertson, and Jere E. Brophy, "An Experimental Study of Effective Teaching in First Grade Reading Groups," The Elementary School Journal, 79 (March 1979), 199; J. Crawford and Jane Stallings, "Experimental Effects of In-Service Teacher Training Derived from Process-Product Correlations in the Primary Grades," Center for Educational Research, Stanford University, Stanford, Calif., 1978, cited in Thomas L. Good, "Teacher Effectiveness in the Elementary School," Journal of Teacher Education, 30 (March-April 1979), 56.

[47] Good and Grouws, p. 356; Stallings p. 17.

[48] See (1) James Greeno, "Research on Cognition and Behavior Relevant to Education in Mathematics, Science, and Technology," in National Science Board Commission on Precollege Education in Mathematics, Science and Technology," Educating Americans for the 21st Century: Source Materials (Washington, D.C.: National Science Foundation, 1983), pp. 107-40; (2) Herbert Ginsburg (ed.), The Development of Mathematical Thinking (New York: Academic Press, 1983); (3) Richard Lesh and Marcia Landau (eds.), The Acquisition of Mathematics Concepts and Processes (New York: Academic Press, 1983); (4) Raymond S. Nickerson, Understanding Understanding (Cambridge, Mass.: Bolt, Beranek and Newman, Inc., 1982).

[49] Robert F. Tinker, "New Dimensions in Science and Mathematics Software," Classroom Computer News, March 1983, pp. 36-39; W. Feurzeig et al., Microcomputers in Education (Cambridge, Mass.: Bolt, Beranek, and Newman, Inc., October 1981).

CHAPTER 4

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

The purpose of this chapter is to examine the feasibility of retraining teachers certified in other fields to become mathematics and science teachers. Retraining teachers already certified in other fields is one of several possible ways of reducing or eliminating a shortage of mathematics and science teachers. If, in fact, teacher knowledge is less important for student achievement than has been assumed as we suggested in chapter 3, then the orderly movement of teachers from other fields into mathematics and science teaching is a realistic possibility.

Another possible solution to teacher shortages that focuses on retraining is training mathematicians and scientists working in or retired from positions in industry. These persons would already possess adequate knowledge in the subject area but would need to be trained as teachers. There are other possible solutions to the shortage problem, such as raising the pay for mathematics and science teachers, waiving state-certification requirements, increasing the use of emergency credentialing, increasing the size of mathematics and science classes, and multiplying the teacher's "reach" through the use of audio-visual aids or computer-based instruction. These options are summarized elsewhere.[1]

In this chapter, we discuss the development of teacher retraining programs and the means we used to identify and analyze existing programs. We discuss the types of programs we identified and examine their varying approaches to funding, candidate selection, and program length. We discuss the criteria by which the effectiveness of retraining programs may be evaluated and the extent to which these criteria can be applied to these programs. Finally, we draw some conclusions from the analysis.

WHAT ARE THE CHARACTERISTICS OF THE NEW RETRAINING PROGRAMS?

Development of retraining programs

Programs to retrain teachers certified in other subjects to become mathematics and science teachers have developed in response to the shortages of qualified mathematics and science teachers combined with a surplus of teachers in some other fields. Enrollments of children have declined in many school districts around the country in recent years, and reductions in force of teachers and reassignments to other subject areas have sometimes occurred. (The American Federation of Teachers estimates that 140,000 teachers have been affected by reductions in force during the period 1981-83.) In some districts, particularly those with union contracts, seniority often determines which teachers keep their jobs when there is an oversupply. Retraining may be a more appealing option than to release some teachers and hire others. Retraining also appeals to those persons who believe that the pedagogical skills of an experienced, dedicated teacher may be more important than content knowledge (see chapter 3), especially where the aim of a retraining program may be to prepare participants to teach basic rather than advanced courses. The major objection to retraining programs is a concern that retrained teachers will lack a depth of knowledge in mathematics or science needed to teach effectively.

Study design and sample selection

We examined literature on mathematics and science retraining programs for teachers and discovered that the literature did not discuss the effectiveness of mathematics and science retraining programs (presumably because such programs have only recently been developed), but it consisted primarily of discussions of the problem and possible solutions. The most useful "literature" for this review consisted of recent speeches or press interviews, position papers, descriptive brochures, and interoffice memoranda that we often obtained directly from those affiliated with retraining programs.

We used a variation of "snowball sampling" to select programs to review. We used snowball sampling because we were faced with the perplexing methodological problem of how to identify the national population of mathematics and science teacher retraining programs. Snowball sampling uses probability methods to select the initial respondents for a survey and then obtains additional respondents from information provided by the initial respondents.[2] Our particular variation of snowball sampling consisted of conducting a telephone interview with an official of each of the existing state-level mathematics and science retraining programs that had been identified in an Education Week article listing such programs and obtaining additional respondents from the initial respondents; that is, we selected each initial respondent with a probability of one and defined existing state-level programs as programs that were in operation or had been funded.[3] The initial state-level respondents referred us to other states that had recently passed legislation covering mathematics and science retraining programs and to school districts and universities that were conducting or planning to conduct such programs. While this methodology does not guarantee comprehensive coverage of all programs or provide a sample systematically chosen from a predefined universe as would more traditional methods, we believe sufficient programs have been identified to discover patterns of commonality and to suggest tentative conclusions, which can be tested as more data on retraining programs become available.

We identified 17 mathematics and/or science retraining programs and interviewed the program managers over the telephone concerning the progress of their projects. The interviews covered the goals of the retraining programs, the procedures used to select participants, the content and length of the programs, evidence of the effectiveness of the programs, and the cost of the programs. We also interviewed officials over the telephone from professional organizations knowledgeable about mathematics or science teaching (National Council of Teachers of Mathematics, National Science Teachers Association, and National Education Association).

Types of programs

For the purposes of this analysis, we classify each program as either a SEA, a LEA, or a university program. In all programs, participating teachers are enrolled in classes aimed at retraining them to teach science or mathematics subjects. A SEA or LEA program is defined as an organized system at the state or local level to provide funding and other support to identify, recruit, and provide training to teachers of other subjects to assist them to be certified as teachers of mathematics or science. Operationally, SEA and LEA programs are funded, which allows students accepted into the programs to enroll in classes free of charge or at minimal cost. University programs are courses of study developed by and offered at universities for which tuition is charged and no financial assistance is systematically provided. In one case the distinction is blurred: the North Dakota State University program is partially funded by the state. However, because it was developed and is controlled by the university, it is more properly considered a university program.

Not all the programs, which were identified by our sampling method, are included in this analysis. Some have been omitted because they were unfunded proposals to conduct teacher retraining. Others are excluded because they were more concerned with training mathematicians and scientists from industry to become teachers, were more properly considered preservice training pro-

Table 7

Retraining Programs Examined

SEA	LEA	University
Florida	Houston, Texas	North Dakota State University
Indiana	Fairfax, Virginia	Southwest Missouri State University
Kentucky		Temple University
North Carolina		Westfield State College
Virginia		

grams for initial certification, or ceased operation.[4] Table 7 lists the 11 programs used in this analysis. To be included in the analysis, a program had to be in operation by September 1983.

We mailed program managers sections of an earlier draft of this chapter that cited their programs, asking them to verify the accuracy of all references. All 11 program managers responded and we made any necessary changes.

SEA Programs

State-level programs to retrain teachers for certification in mathematics or science teaching are a recent development. State funds are provided either directly to retraining institutes, generally schools of education, to furnish retraining services to successful applicants certified in other fields, or are given directly to teachers in the form of a grant or loan. Some states use a combination of both approaches. North Carolina, for example, is funding 20 teacher institutes during the summers of 1983 and 1984 to facilitate certification of current 7th- and 8th-grade mathematics and science teachers who are teaching without appropriate certificates. The institutes are offered at various teacher training institutions throughout the state. Programs were developed under SEA guidance by the institutions in conjunction with LEA's and were designed to meet local needs. A total of 492 teachers were selected from 900 applicants by a committee of institution and LEA staff on the basis of principals' recommendations, extent and recency of mathematics/science training, and current teaching load. (Selection criteria are discussed more in detail below.) Participants will receive six college credits applicable toward certification for each summer and $35 per day for expenses. The state also pays the instructors. (North Carolina also provides $1,000 scholarships to mathematics/science teachers to upgrade their skills. Only appropriately certified secondary school teachers are eligible for this assistance.)

Virginia has recently initiated a combined summer institute/direct loan program for mathematics teachers. Four universities each received $10,000 grants to operate summer institutes to retrain certified teachers from other disciplines (or to upgrade the training of currently uncertified mathematics teachers, a subject beyond the scope of this chapter). During the 1983-84 school year, the SEA will also pay $450 of tuition costs (in the form of a loan to be forgiven after 2 years service) for teachers working toward mathematics certification. Virginia is also the only SEA identified as providing a retraining grant to an LEA. Fairfax County has received grants totalling $15,500 to develop an LEA program to conduct a local mathematics institute for its teachers in need of certification.

Other states rely exclusively either on grants to teacher training institutions or on direct loans to teachers. In July, 1983, Indiana established the "Indiana Teacher Shortage Financial Assistance Fund" to provide reeducation grants or interest-free loans of up to $1,000 to certified teachers from other disciplines to fulfill certification requirements in designated shortage areas (including mathematics and science). Kentucky has established two loan programs for mathematics and science teachers: a summer program for active, certified teachers from other disciplines and a full-time, academic year program aimed mainly at undergraduate education students but open to certified teachers seeking mathematics or science certification. Although loans are made directly to teachers in Kentucky, the SEA monitors the program by overseeing the course of studies at institutions approved for participation, allocating "slots" at participant institutions, and specifying criteria to be used by institutions in selecting students and recommending them for loan approval. Loans for full-time programs are $2,500, for summer programs $833. Academic year loans are repayable by a year of teaching mathematics or science in a Kentucky public school; summer school loans are repaid by one semester's teaching. Florida's program, on the other hand, awarded a total of $286,530 to eight state universities to provide programs adapted to local requirements either to upgrade the skills of certified or uncertified mathematics or science teachers or to facilitate certification of competent mathematicians and scientists who do not meet pedagogical requirements for certification in the state.[5]

LEA programs

Teacher retraining programs have also been initiated at the local level. One of the most developed LEA programs is conducted by the Houston, Texas, Independent School District. Entitled Project Search, it is one component of a broader program to remedy a shortage of mathematics and science teachers in Houston schools. Project Search recruited 100 teachers from different subject areas or teaching levels for retraining in mathematics and science. In conjunction with local universities, Houston developed and implemented individualized programs to prepare elementary teachers for certification at the middle/junior high level and middle/junior high teachers at the secondary school level. Course instructors are mathematics teachers, science teachers, or supervisors, and classes are taught at Houston Community College, a part of the Houston Independent School District. Tuition and books are paid for by the LEA, which also provides a $250-per-course stipend to teachers if they receive a grade of B or better. Program participants must commit themselves to teach in Houston for 3 years.

In summer 1982, Fairfax County, Virginia, began a retraining program in mathematics for teachers in its district. Through an arrangement with a local community college, participants take the same series of subject-matter courses as undergraduate majors in mathematics education. Classes are offered at a convenient time for teachers who take one course per quarter and two during the summer. After 2 full years, graduates will have fulfilled all requirements for Virginia certification as secondary mathematics teachers. Fairfax County has also included a master teacher component in the program: experienced mathematics teachers are available for assistance and demonstrate model lessons in their classroom. The program is offered free of charge, but participants must sign a contract to accept any available mathematics teaching slot after graduation.

University programs

Some programs to retrain teachers certified in other fields as mathematics or science teachers have been developed at universities without funding. Of the programs investigated, all were designed to meet state certification standards, and most were for mathematics teachers. Variations exist in the length of programs, partially because of the varying state certification requirements but also due to the varying levels of program intensity. In the summer of 1983, North Dakota State University in Fargo launched a two-summer program in mathematics consisting of a series of intensive 2-week courses. At the end of the program, teachers will be fully certified to teach mathematics at the secondary level in North Dakota, which requires only 16 semester hours of preparation. Southwest Missouri State University in Springfield, Missouri, offers a mathematics program of similar length but more traditional in individual course length. Over two summers, participants take five courses. While these are not sufficient for permanent certification in themselves (Missouri requires 30 credit hours for certification in secondary mathematics), they qualify a teacher for temporary certification, which only requires 12 hours.

Westfield State College in Westfield, Massachusetts, conducts an intensive retraining program for certification in mathematics and mathematics/science. Thirty-nine credit hours can be earned over 9 months of evening and weekend classes. By contrast, Temple University in Philadelphia offers a 3-year program, which consists of nine courses conferring 27 credits.

Candidate selection

Criteria for admitting candidates are expressed most formally in the Kentucky program, where a regression equation was written by the SEA for use by universities in rank ordering candidates. The Kentucky criteria, however, were applied in some fashion by most SEA and LEA programs:

--prior mathematics/science coursework: most programs understandably seek candidates who have already accumulated some academic credits in the field; the certification payoff is quicker. Kentucky applies inverse weighting to the number of hours required for certification; weights range from 1.0 for 10 hours or less less to 0.6 for more than 40 hours.

--undergraduate academic performance, as determined by review of personnel folders or college transcripts. Preference is given to applicants with more successful academic history.

--past job performance, usually determined by recommendations of principals or other supervisors or, as in Houston, by a quantitative score on an annual assessment scale. Teachers with higher performance ratings are preferred.

Kentucky expressly includes differential weights for the particular field studied (from 1.0 for physics to 0.6 for biology), reflecting the state's need for teachers in different disciplines. It may safely be assumed that other jurisdictions at least implicitly consider the perceived needs of the SEA or LEA. in selecting candidates. Fairfax County administers a test used by the community college as a screening test for a calculus course and discourages applicants who score poorly. Indiana gives explicit preference to teachers laid off by reason of reductions in force.

The selection process in the university programs investigated was less stringent. The Temple and the Southwest Missouri State programs require previous college mathematics courses for admission.[6] Temple University administers an aptitude test to applicants. Temple uses 70 percent as a "guideline" for admission but has no firm cutoff score. Westfield State College offers a test to help applicants decide about entering the program. Essentially participants appear to be self-selected with some counseling assistance provided by the universities. An official of one university program felt that actual performance in the program provided a significant selection criterion and viewed the first course in the program sequence as a means of screening out less promising participants.

Length of program

We found great variation in the time needed to complete retraining programs. Some, like North Dakota State University and Southwest Missouri State University, are two-summer programs. The Westfield State program takes 9 months, but the Temple University program takes 3 years to complete. Several factors combine to effect this variation:

1. certification requirements. A great variation exists among states in the amount of preparation required for teacher certification. In the states where our training programs are located, the number of college credits required for teaching mathematics or science at the

secondary level ranges from 16 in North Dakota to 48 in Kentucky.

2. certification status at program completion. Some programs in effect guarantee certification at their conclusion. These are typically longer programs or ones with high admissions standards. North Carolina aimed at getting the teacher sufficiently close to certification that the teacher can complete the requirements.

3. entry standards. Some programs, particularly those developed independently by universities, accept candidates with fewer previous mathematics or science courses than do typical LEA or SEA programs.

4. intensity of program. Some programs are quite fast-paced and demanding. Westfield State, for example, packs 39 credit hours into 9 months of evening, weekend, and summer classes but attracted few students. Temple University spreads 27 credits over 3 years.

The actual time needed to complete a program is determined by an interaction of these factors, which are largely under the the control of the program designer. If a crash program were needed and adequate funds were provided to the institutions to develop and conduct the training and to teachers for tuition, books, and living expenses, it is likely that any of the programs described here could be conducted on a full-time, intensive schedule. If a more gradual approach seemed preferable, the programs could be adjusted to allow part-time participation at a less intense pace.

HOW EFFECTIVE ARE THE NEW RETRAINING PROGRAMS?

The ultimate goal of all teacher retraining programs is to increase the supply of competent, knowledgeable, and effective teachers in the shortage areas of mathematics and science. Different criteria of program success could be used. Criteria include retention in the program, success in obtaining appropriate teaching credentials (certification), subject-matter mastery, continuation in teaching, and quality of teaching performance by program graduates. The programs we investigated are all too small and too new to provide adequate data on which to base solid generalizations. Some anecdotal evidence, however, was available.

We review the available evidence and then discuss both the training and retraining findings including the logic of our comparisons of the two very different data sources.

Retention in the program

Data regarding the rate of program completion were not available from all programs, since many are only in their initial stages. In general, programs funded by SEA's or LEA's experienced relatively high retention rates in comparison to university programs. Houston, for example, has experienced a 90-percent retention rate. Nearly two-thirds of the first cohort are still enrolled in the Fairfax County program. In the SEA programs, Kentucky reports retention of 85 out of 90 who enrolled in 1982 and Virginia indicates that 62 of 65 teachers are continuing in its program. North Carolina reports a high percentage of teachers completing the summer training session in 1983.[7]

By contrast, Temple University expects at least 35 to complete the 3-year program but only 46 of the original 83 enrollees remained after the first year. At Westfield State, publicity surrounding the start of the program attracted 400 inquiries, but the program started with only 15 students, and only 5 or 6 are expected to complete the program. The retention rate reported from university programs averaged less than 65 percent and the final figure may be lower since the figures include students still in training.

The higher retention rate experienced by SEA and LEA programs is most likely attributable to more careful screening of applicants and to the fact that they are offered at little or no cost to participants. To some extent also, the fact of being selected by their superiors may provide a certain status in the eyes of the participants and their peers, which enhanced other motives. Participants in university programs lack such reinforcement and need a much higher level of motivation to continue expending their own time and money. While these university programs may seem to have a natural appeal for teachers who are either unemployed or in danger of being laid off, it is doubtful that teachers who have freshly realized the insecurity of their employment future would be strongly motivated to undertake an expensive and demanding program to be able to continue in teaching if alternative employment were available. Furthermore, higher attrition rates would seem of less concern to universities than to SEA's and LEA's who must view their programs as investments of scarce resources. LEA's and SEA's are naturally more highly motivated to minimize costs by screening out applicants unlikely to complete the programs in a reasonable time. The implications of this for federal aid are discussed in chapter 6.

Certification

The operational goal of all programs is to achieve certification for their participants. All programs either qualify students for appropriate certificates or, like North Carolina, provide sufficient progress toward certification that the student may reasonably be expected to complete requirements after completion of the program. It is reasonable to assume that most program graduates will apply for and receive certification and thus swell the numbers of certified mathematics and science teachers.

Houston's Project Search appears to have been remarkably successful in alleviating the shortage of certified teachers. In 1978, there were 13 secondary science vacancies and 34 mathematics vacancies. On September 1, 1982, there were only 2 mathematics vacancies and 1 science vacancy in Houston. This result cannot be attributed exclusively to Houston's retraining program, although 34 of the program's graduates have already been placed in mathematics and science classrooms. Houston's Second Mile program, of which Project Search is one component, is a vigorous, stipend-oriented response to teacher shortages and subpar performance. Certified teachers of mathematics and science (and certain other fields) receive a $2,000 salary differential. Additional stipends are available for attending in-service programs or taking subject-related college courses. After the introduction of Second Mile, improvements in teacher turnover rate and absenteeism, as well as a dramatic reduction of vacancies in critical shortage areas, occurred. It would thus be impossible to disentangle the main effects of each treatment on teacher shortages, but there would seem little doubt that Project Search contributed substantially to increasing the supply of qualified mathematics and science teachers. It must be noted, however, that such radical changes in the system of teacher remuneration as are represented by Second Mile may be impossible to implement in LEA's with established collective bargaining agreements.

Subject-matter mastery

No objective data are available to compare program graduates on subject-matter mastery with teachers trained more traditionally or with some established standard. The director of the Temple University program suggested that its graduates may not possess mathematical skills equivalent to the graduate of a mathematics education program but would be fully qualified to teach junior high and basic high school courses. It could be argued, however, that graduates of retraining programs would be more knowledgeable about recent developments in the field than veteran teachers who have not updated their skills for several years.

Quality of teaching and continuation in teaching

The critical criteria by which to judge the success of retraining programs are whether they produce qualified, effective classroom teachers and whether these teachers remain in teaching for enough years after completing retraining to justify the expense of retraining. The retraining strategy assumes that experienced teachers from other disciplines are better risks by both criteria inasmuch as their prior service is some indication of their competence in the classroom and their interest in teaching. (LEA and SEA programs, which use performance evaluations as factors in the selection process, reduce these risks further.) Unfortunately, no objective data are yet available from our programs on these ultimate criteria of program success.

Assessing training and retraining programs

Here we review the effectiveness findings of this and the previous chapter and lay out the logic of our comparisons of the two very different sets of data.

We note in chapter 3 that research to date has failed to show a straightforward relationship between teachers' knowledge and the subsequent learning by their students in mathematics and science. Since that research was conducted, increases in the supply of uncertified mathematics and science teachers have been reported (see chapter 2), raising the possibility that uncertified teachers now in or coming into classrooms may benefit from training or retraining programs in ways that fully certified teachers do not. This follows since the inconclusive findings for upgrading training may be based upon a group of better qualified teachers. Also, if uncertified teachers really have grave weaknesses in subject matter knowledge, they have the most to gain from content instruction.

Whatever the prior preparation and knowledge levels of teachers entering retraining programs may be, we found in this chapter that retraining programs succeed in attracting and enrolling applicants, retaining enrollees, and starting to graduate teachers who are eligible for certification. Retrained teachers may or may not be of the same quality as existing mathematics and science teachers. Retraining programs have simply been too new to make such comparisons, although that research should now be possible. We have no particular reason to assume that one brand of certified teacher will be less knowledgeable or less effective than another, especially since student achievement is not very sensitive to differences in teacher knowledge. However, data to test this proposition are not available.

The retraining strategy is certainly promising in terms of helping to solve teacher shortage or quantity problems. The quantity problem may be more successfully dealt with because it is a simpler problem than teacher quality. Certification is a process that defines minimal or threshold quality. The shortage problem is by definition solved once there are certified teachers in the classrooms. Retraining programs seem to be helping to increase the supply of certified teachers.

As a final note, observe that the line of argument in this subsection would not have been possible if programs to upgrade teachers had shown evidence of effectiveness in improving student achievement. In that case, the burden of proof would have been upon the new retraining programs to demonstrate that they could achieve results as good as the (hypothetically) good results of upgrading programs.

SUMMARY AND CONCLUSIONS

In this chapter, we reported the results of examining 11 programs to retrain teachers certified in other fields to teach mathematics and science. We discussed the means we used to identify retraining programs. We categorized the programs as SEA, LEA, or university programs and discussed their different approaches to funding, candidate selection, and program duration. We suggested criteria for evaluating the effectiveness of retraining programs and applied them to the programs in our sample.

The programs we reviewed were limited both in number and in years of experience. Nevertheless, some common threads emerge from our analysis to suggest the following preliminary findings:

1. Teacher retraining programs can be expected to increase the supply of certified mathematics and science teachers. The immediate goal of all the programs we reviewed is to provide their participants with most, if not all, of the requirements for certification in their state as mathematics or science teachers. 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.

2. University retraining programs tend to suffer from lower retention rates and therefore seem an unreliable source of newly qualified teachers. The decision to enroll and to stay in these programs is probably highly sensitive to economic conditions, particularly to the threat of teacher layoffs in other fields and the lack of alternative employment. In contrast, SEA and LEA retraining programs experience higher retention rates, in part due to their more careful screening of applicants.

3. Combining funded retraining programs (such as the current ones offered by SEA's and LEA's) with other incentives appears to provide an effective strategy. Stipends for participating in retraining programs and salary increases for teaching in shortage areas may offer the quickest solution in communities with severe shortages. However, the appropriate size and mix of incentives can only be determined by a careful assessment of the extent and urgency of the shortage. Finally, the viability of this strategy will be affected by the local collective bargaining situation.

4. Insufficient information exists at present to predict the quality of on-the-job performance by retrained teachers. Some have suggested that they will be less qualified than traditionally trained teachers, but it can be argued that they may be superior in some respects.

5. There was wide variation in the length of time needed to complete retraining in the sampled programs: they ranged from 9 months to 3 years. Despite this variability, program length can be controlled by policy intervention based on the urgency of the teacher shortage. In the absence of substantial scholarship and subsistence payments, short and intensive programs seem to attract few students. Thus it is likely that shorter programs will prove more costly.

NOTES

[1] James W. Guthrie and Ami Zusman, "Teacher Supply and Demand in Mathematics and Science," *Phi Delta Kappan*, September 1982, pp. 28-33. See also K. Forbis Jordan, *Teachers for Precollege Mathematics and Science Programs* (Washington, D.C.: Congressional Research Service, July 28, 1982).

[2] S. Sudman, *Applied Sampling* (New York: Academic Press, 1976), pp. 210-11.

[3] *Education Week*, May 18, 1983.

[4] The programs not included are the South Carolina SEA, Philadelphia, University of Vermont, Fordham University, Catholic University, and the Greenville (South Carolina) LEA.

[5] Florida officials informed us that the programs will now be handled on a local level instead of the state university system.

[6] Southwest Missouri States' program is designed for teachers already certified to teach elementary school mathematics in Missouri. Teachers would have taken previous mathematics courses to gain this certification.

[7] North Carolina reports that 479 out of 488 teachers completed the summer training programs.

CHAPTER 5

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

In this chapter, we note the weaknesses in available data about programs to improve mathematics and science teaching as well as in assessments of the severity of quality and quantity problems in mathematics and science teaching. We then discuss some priorities for evaluation under both teacher quality and teacher quantity in the context of pending legislation.

WEAKNESSES IN PAST EVALUATIONS AND NEW EVALUATION PRIORITIES

We have noted throughout this report critical limitations in the availability of essential evaluative information. In the case of retraining programs, the problem lies in part in the lack of prior experience with this mechanism. However, we also noted no systematic evaluation efforts in this area, perhaps due to the current absence of any national level funding in this area. In the case of upgrading existing science and mathematics teachers, part of the evaluative problem lies in the weakness of past evaluation efforts. We believe such efforts should be conscientiously improved with any new programs enacted in mathematics and science education.

It was not one of the objectives of this report to assess the evaluation function within NSF. Nevertheless, many of the available studies we reviewed in chapter 3 were funded by NSF. We found that NSF studied the participants in institutes, but there was only a modest amount of work initiated in the outcomes of NSF institute programs and no comparison of the relative effectiveness of different institute approaches. A broader evaluation program could have helped guide the changes in policies and funding decisions that took place over the years at NSF.

We often found weaknesses in the policy orientation of funded evaluations. For example, the single study of non-applicants, successful applicants, and rejectees did not analyze the data by type of institute. Given the expectation of different audiences for the different types of institutes, this method of analysis may well have obscured important differences between institute types. Part of the reason for the very low quality of most of the research we did locate on the effectiveness of NSF institutes was that it was largely unfunded and conducted as doctoral dissertation research by graduate students with all the attendant compromises of time, sample size, and design.[1]

The proposed legislation to provide federal aid for mathematics and science education (see chapter 2) does not provide for evaluation of all proposed programs. Neither House of Representatives 1310 nor Senate 1285 appears to include funding for NSF evaluation.[2] Department of Education program evaluation could be supported under a provision in the Senate bill authorizing the National Institute of Education up to $3 million each year for the following research and evaluation activities:

> "(A) a policy analysis of alternative methods to improve instruction in mathematics and science;
>
> (B) an annual evaluation of the programs assisted under this title; and
>
> (C) research on improving teacher training, retraining, inservice training, and retention, as well as the development of curriculum and materials in the fields of mathematics and science."[3]

The limited evaluation support provided in these bills combined with budgetary pressure limiting the availability of other agency funds lead us to conclude that it may never be known whether or not programs enacted are effective. This may be of concern to the Congress especially given the major information gaps we discuss in earlier chapters. These gaps include the lack of documentation of whether or not there is a mathematics and science teacher shortage and direct evidence on the quality of mathematics and science teachers.

Early in any newly enacted program, there will be a need to inform the Congress of basic evaluative information regarding the programs funded. NSF and the Department of Education could plan early studies on the allocation of funds (including substate allocations), needs identified, activities undertaken, an assessment of what teachers receive what type of training, and the match between available funds and training needs. There are many different service delivery mechanisms for training authorized under the bills, which makes a coordinated national level effort to assess resource needs especially important. We saw evidence that by 1964 the NSF institutes were addressing popular but perhaps marginal needs such as institutes for very recent graduates of teacher preparation programs and institutes aimed at providing teachers with master's degrees.

Evaluation priorities for teacher quality

The first priority for evaluation in respect to teacher quality issues in our view is a needs assessment of teacher quality.[4] The data available, as we pointed out in chapter 2, are achievement test scores of teachers in general but not of science and mathematics teachers. We know little about the knowledge levels of mathematics and science teachers and whether or not they are out-of-date in their subject matter area. How much can we learn from the National Teacher Examinations and similar state tests, which have recently been required for entering teachers in many states, especially in the South? New nationwide data collection on teacher quality may be necessary. If the results are to give a national portrayal of the status of mathematics and science teaching quality, collection of comparable data across the country would be a real necessity.

We know that many new mathematics and science teachers lack certification upon entry, but we know little about how many courses they do have in science and mathematics, how many stay teaching science and mathematics for more than one or two years, and what subsequent coursework these teachers take in science and mathematics. In short, we known very little concretely about how serious a problem we have in science and mathematics teacher quality and to what extent it is a nationwide problem.

If the proposed legislation is enacted, there will be more dollars and a greater variety of remedies than in past programs. This will provide more opportunities for alternative strategies, but it also increases the need to plan nationwide evaluations that address the effectiveness of the remedies.

Figure 1 (see page 60) serves to conceptualize the factors that could be considered in program evaluations that are intended to improve teacher quality and subsequent student achievement in mathematics and science. We begin this discussion by noting that the level of student achievement in mathematics and science--the outcome entry at the far right of figure 1--is better documented than the other topics we have reviewed. The testing program of the National Assessment of Educational Progress funded by the Department of Education has provided a useful yardstick of student achievement in science and mathematics at ages 9, 13, and 17. Data from standardized tests--especially in mathematics but also in science--provide other indicators of how much students know.[5] The National Science Board Commission on Precollege Education in Mathematics, Science and Technology has recommended the development of a national assessment that allows national, state, and local comparisons in contrast to the national level reporting under the National Assessment of Educational Progress.[6] This effort would presumably replace the National Assessment.

The measurement of the other factors or influences shown in figure 1 is much less developed. We know too little about how effective teaching can increase student achievement or how a factor such as effective teaching interacts with other factors such as student characteristics, school organization, and school culture. Another complication is that multiple programs are funded to increase teaching effectiveness and they are introduced at many points of influence. Programs to increase the

Figure 1
A Model of Influences on Teacher Quality and Student Achievement

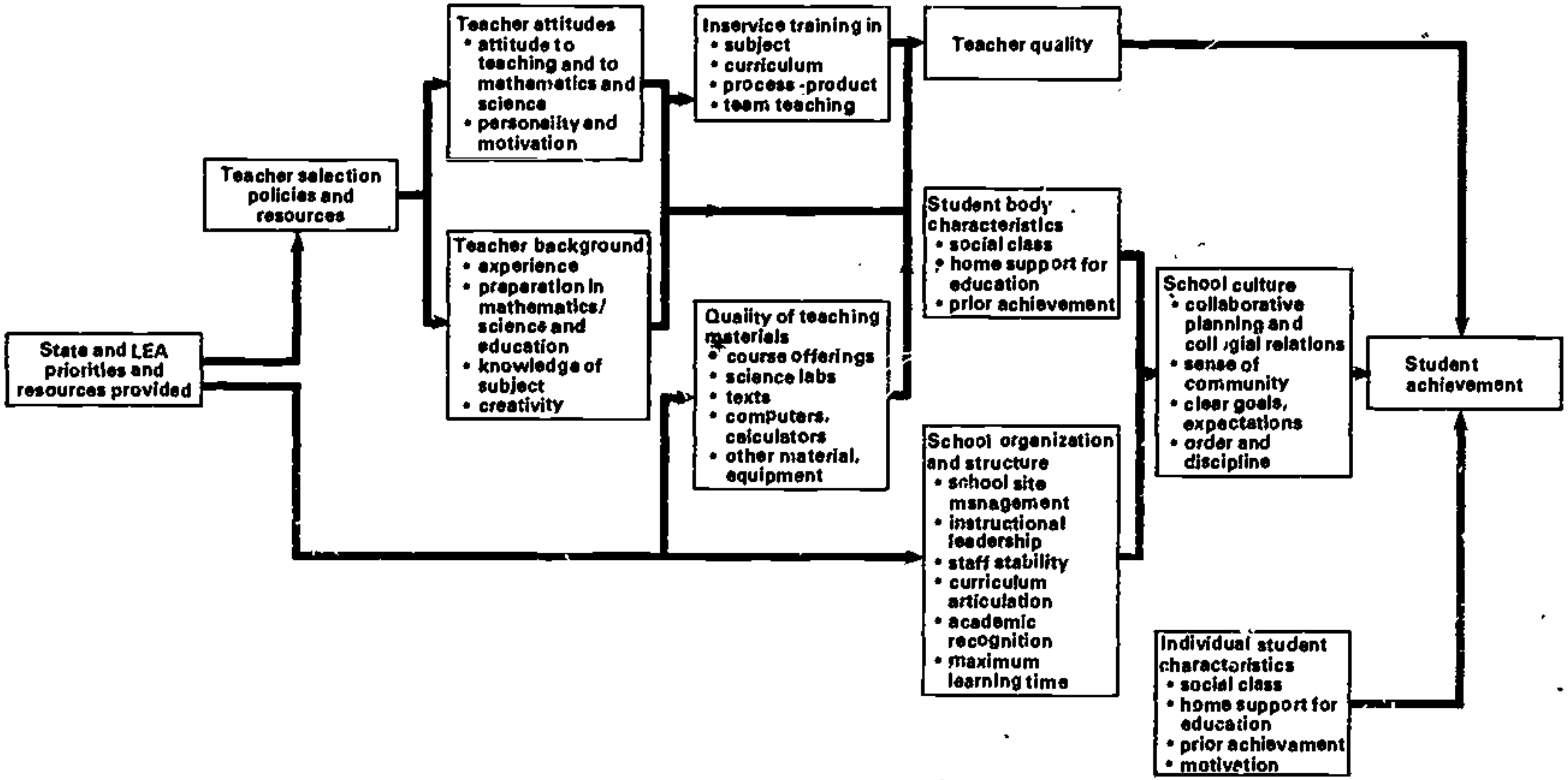
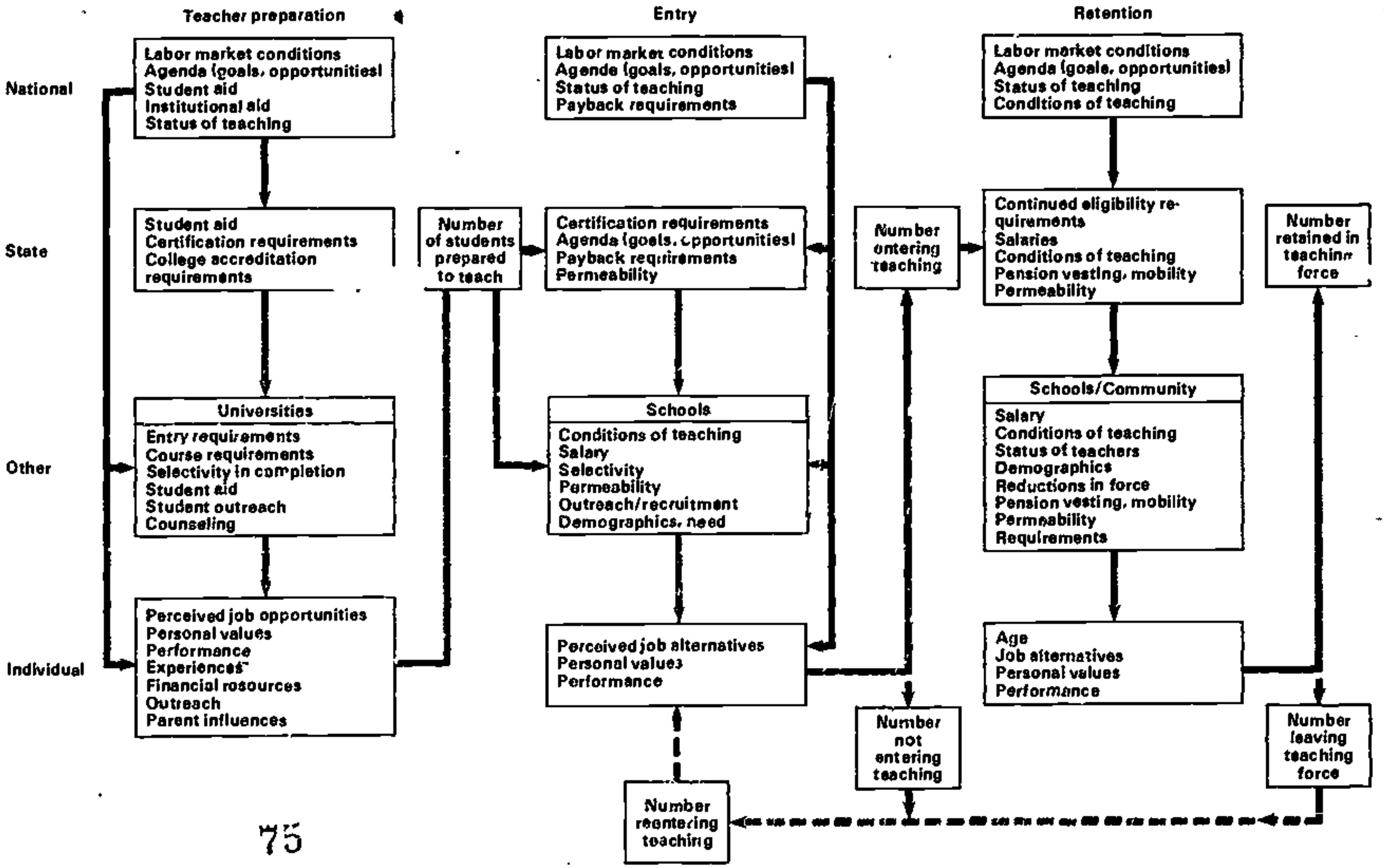


Figure 2
A Model of Influences on Teacher Quantity



quality of teaching materials in the schools as well as in-service training programs will be occurring simultaneously within schools. Evaluation needs to be spread over all programs if impacts are to be traced and if any assessment is to be made of relative effects and consequent needs for priority-setting.

Evaluation priorities for teacher quantity

The first priority in our view regarding the shortage of mathematics and science teachers is to address the problem of seriously flawed available data on the extent of the shortage. This is not a matter of purists quibbling over minor weaknesses in data. As we noted in chapter 2, the shortage statistics are based on opinion surveys, partial examinations of the total prob-lem (such as the number of newly certified graduates in each field each year), and imprecise data on numbers of teaching vacancies. Efforts to assess the impact of new federal legislation would seem to require good data on the extent of shortages and changes over time. We are encouraged that the National Academy of Sciences is active in examining this
problem, but we know of no planned recurring nationwide data collection that will meet the needs we have cited above.

Figure 2 serves to conceptualize the factors, which affect the number or quantity of mathematics and science teachers. Student aid programs funded by federal, state, or university sources affect both initial decisions of students to prepare to be teachers (the first column of the figure) and subsequent decisions on entering the field of teaching (middle column of the figure). The latter decisions are presumably affected by the nature of the payback requirements contained in student aid programs. A second possible evaluation area--in addition to the measurement of the shortage as just discussed--concerns the impact of scholarships. It may be useful to expand upon the work done in this area for previous loan forgiveness and service payback programs by the Congressional Research Service.[7]

A third possible area of evaluation--also represented in the middle column of figure 2--is an examination of successful and unsuccessful efforts in filling mathematics and science teacher vacancies. Some observers have suggested that it is the dual effects of low pay and low morale and status of teachers that inhibit recruitment and retention. Even if only one of these barriers can be reduced, some maintain, the effects on teacher supply will be substantial.

A fourth important consideration is an examination of why science and mathematics teachers stay in teaching. The right-hand column of figure 2 shows some of the factors that can influence teachers' decisions to remain in the classrooms. It is important to learn what makes some schools more successful than others in retaining teachers. How effective are new federal efforts aimed at teacher recognition in this regard? What it is that attracts former teachers to reenter teaching after childrearing and other careers is a potentially important influence on the quantity of mathematics and science teachers. This element is represented with the dashed lines at the bottom of figure 2.

Finally, in chapter 2 we cited a variety of programmatic attempts to increase the quantity of mathematics and science teachers. If the evaluation of teacher retraining programs is at all representative of the state of evaluation of all programs for increasing the quantity of teachers, the evaluation gaps are serious. We need to know more about who is attracted to such programs, conditions of programs that enhance their appeal, the comprehensiveness of retraining courses compared with standard coursework, and the effectiveness and limitations of retrained teachers.

SUMMARY

The information gaps in mathematics and science education are extensive. We have little confidence in available data on the extent and nature of teacher shortages in mathematics and science. Data on the quality of mathematics and science teachers--and whether or not the quality of technical teaching has declined--are similarly flawed. We also lack a body of solid evaluations of federal programs to improve mathematics and science education. We argue that the limited evaluation support in proposed mathematics and science education legislation may mean that it will not be known whether or not programs enacted under this legislation are effective. In the next chapter, we summarize our observations.

NOTES

[1] Marilyn N. Suydam and Alan Osborne, The Status of Pre-College Science, Mathematics, and Social Science Education: 1955-1975, vol. 2, Mathematics Education (Columbus, Ohio: Center for Science and Mathematics Education, Ohio State University, 1977), p. 170. In his review of 138 documents on institute effects in 1974, Helgeson found that 63 or 46 percent were theses or dissertations. See Stanley L. Helgeson, "Impact of the National Science Foundation Teacher Institute Program," University of Minnesota, Minneapolis, 1974, p. 2.

[2] The House bill authorizes $5 million each year for NSF research, but this does not appear to include authorization to evaluate NSF programs. H.R. 1310, March 2, 1983, sec. 105 and 107(b).

[3] S. 1285, May 16, 1983, sec. 212(b)(2).

[4] Some similar suggestions are presented in Nancy B. Borkow and K. Forbis Jordan, The Teacher Workforce: Analysis of Issues and Options for Federal Action (Washington, D.C.: Congressional Research Service, November 7, 1983), p. 28.

[5] Lyle V. Jones, "Achievement Test Scores in Mathematics and Science," *Science*, July 24, 1981, pp. 412-16.

[6] 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), pp. 11-12.

[7] Jim Stedman, *The Experience with Loan Forgiveness and Service Payback in Federal and State Student Aid Programs* (Washington, D.C.: Congressional Research Service, 1983).

CHAPTER 6

OBSERVATIONS

In this chapter, we consolidate our major observations on improving the quality and quantity of mathematics and science teaching.

QUALITY AND QUANTITY PRIORITIES

Our 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 since the appearance of a substantial number of uncertified teachers may be a recent phenomenon. In addition, the uncertified teachers represent the group in greatest need of subject matter training. This approach would differ from the prior NSF strategy and would require careful planning for successful NSF implementation.

Solutions to the teacher quality and quantity problems are to some degree in opposition. Calls for increasing quality standards exclude more teachers from the classroom and delay the entry of others.

Programs to deal with teacher quantity or shortage problems offer more promise than efforts to improve teacher quality. We found that teacher retraining programs can increase the supply of certified teachers. Retention data from a few programs suggest that it will be possible to graduate a reasonable number of those who enter.

The quantity or shortage problem may be more successfully dealt with because it is a simpler problem. Historically, we have defined qualification for teaching by certification. In this sense, our quality and quantity categories become a bit blurred. Certification is a stage that defines minimal or threshold quality. The shortage problem is by definition solved once there are certified teachers in the classrooms.

Teacher quality is a separate and seemingly more intractable issue. Once teachers have passed some threshold of knowledge through certification, can we further increase their subject matter knowledge? And if we do, does it help students? To treat completion of institutes or other upgrading training as the equivalent of completion of certification would be to ignore the absence of much evidence of a demonstrable educational value of such training in improving student achievement.

From an evaluation perspective, the point is that the teacher quantity and quality questions are different in level of difficulty. While criteria of completion of training are adequate for the former, the latter requires more rigorous criteria. The implication of this observation is that the certification or quantity issue is more immediately susceptible to intervention than improving teacher quality.

While our findings on teacher upgrading do not encourage a substantial investment in such activities, there could be other teacher quality approaches that are more promising. We did not examine the approaches oriented toward equipment, materials, and program improvement that are part of the remedies the Congress is considering. We also note that school quality improvement stategies such as magnet schools and gifted and talented student programs are alternatives.

HOW MUCH TIME DOES IT TAKE TO RETRAIN TEACHERS?

There was considerable interest in the Congress over the issue of how much time it takes to retrain teachers for mathematics and science classrooms. In practice, we found wide variation in the length of time to complete retraining programs ranging from 9 months to 3 years. The North Carolina SEA program requires only two summers because it has the objective of getting teachers close to certification, leaving the final steps to the teacher after the program. Shorter programs also insist on more completed mathematics or science courses for admission. The SEA and LEA programs in particular are likely to require more prior coursework in order to lower their costs and maximize student retention in the programs. In the absence of substantial scholarship and subsistence payments, full-time programs seem to attract few students. Program length is thus highly variable but can be controlled by policy intervention. It is likely that shorter retraining programs will be more costly through both scholarship and subsistence costs.

STRUCTURING EFFECTIVE RETRAINING PROGRAMS

University retraining programs tend to suffer from lower retention rates and therefore seem an unreliable source of newly qualified teachers. The decision to enroll and to stay in these programs is probably highly sensitive to economic conditions, particularly to the threat of teachers layoffs in other fields and the lack of alternative employment.

Combining LEA or SEA funded retraining programs with other incentives appears to provide an effective retraining strategy. Stipends for participating in retraining programs and salary increases for teaching in shortage areas may offer the quickest solution in communities with severe shortages. The appropriate size and mix of incentives can only be determined by an assessment of the extent and urgency of the shortage, and the viability of this strategy will be affected by the local collective bargaining situation.

The SEA and LEA retraining programs experience higher retention rates than university programs, in part due to their more careful screening of applicants. The SEA's and LEA's are concerned about attrition since they are paying for the retraining. This suggests that the strategy in the proposed mathematics and science legislation of requiring linkage between universities and school districts in training programs may be productive.

PROCESS-PRODUCT APPROACHES

The efforts of process-product researchers to identify effective teaching behaviors and to develop teacher training programs around those findings offer promising possibilities. The approach has been limited to mathematics and reading and could be attempted in science teaching. Also, the bulk of the effort has been conducted at the elementary grade levels. It may be useful to devise a secondary level research program beginning with the identification of effective secondary level teachers and correlates of successful teaching.

GAPS IN EVALUATIVE INFORMATION

The gaps in evaluative information are so serious that we conclude that even the question of whether or not there is a net nationwide shortage of mathematics and physical science teachers is inadequately documented today. Similarly, data on the quality of existing mathematics and science teachers are based on surrogate measures of quality such as certification status or on test scores of teachers in all fields rather than mathematics and science teachers.

There are two corresponding informational 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 both hinder the enactment and administration of effective federal remedies and retard appropriate evaluation of the success of new federal remedies.

We found little evaluation of the past NSF institute programs and essentially no national level evaluation of the various retraining initiatives. The limited evaluation support provided for programs in pending bills to aid mathematics and science education combined with budgetary pressure limiting the availability of other agency funds lead us to conclude that it may never be known whether or not programs are effective.

SOME METHODOLOGICAL ASPECTS OF NSF INSTITUTE EVALUATION

Selection of an effectiveness criterion

In our examination of NSF institute effectiveness, the criterion we selected was impact on student academic achievement. Student achievement has been the major educational outcome variable among education evaluations. It represents the most fundamental goal of our education system and, directly or indirectly, of most education programs at the precollege level. There is a long history of the development and application of measures of student achievement in order to measure student and school progress. Thus, achievement can be measured with greater validity and reliability than some other outcome measures. Finally, a focus on student achievement is consistent with the concerns raised by numerous commissions during 1983 calling for improvements in American schooling. The chief practical disadvantage is the time and expense in locating, sampling, and testing students of the former institute participants. The gap in time between the acceptance of applicants into institutes and the subsequent achievement of students requires data analysis that carefully accounts for other extraneous factors that will affect student achievement or an experimental design that randomizes the influence of other factors.

Other outcomes of institute effectiveness have been studied. Some investigators have examined student attitudes toward mathematics or science. The difficulty lies in the questionable validity of measures of student attitudes.[1]

The impact of NSF institute attendance upon numerous teacher outcomes has also been studied. Measures of teachers' attitudes toward mathematics and science or toward teaching have been studied. In our opinion, they share the technical problems of the comparable student measures. Since the rationale for such criteria lies in desired impacts on student behavior (higher student achievement, interest in science, coursetaking), it seems more direct to use student measures. A second teacher outcome is subject matter competence or knowledge of mathematics or science attributable to institute attendance. This can be measured through a variety of standardized or constructed tests. While short-term changes are relatively simple to measure (pre- and postcomparisons during the period of the institute), longer-term gains in knowledge seem much more significant than information recalled at the end of a course. Studies of longer term effects do not seem to have been conducted.

A third teacher outcome concerns the retention of upgraded mathematics and science teachers in the classrooms or in education-related occupations. Retention rates can be measured rather directly through questionnaires mailed to former institute participants and comparison teachers. However, the salary and morale problems discussed in chapter 2 may be changing patterns of teaching careers and teacher retention. One could argue that if teachers leave the field of teaching after about five years, this is not necessarily undesirable since short-term teaching careers may be a realistic goal for recruiting future mathematics and science teachers.

Fourth, some have argued that institutes served to increase teachers' professional stature in their schools. Fifth, institutes may lead to increased professional activity afterwards. While these outcomes are desirable, they are not likely to be considered significant enough to justify an institute program.

Next we describe our procedures for searching for studies of the academic effects of NSF institutes.

Search methods and selection criteria for studies

The procedure we followed in searching for studies of the impact of NSF institute training on the subsequent achievement of the participants' mathematics or science students included the following:

1. the ERIC data base.
2. bibliographies from a 1974 synthesis and two syntheses done for NSF in 1977.[2]
3. interviews with major authors of earlier works, researchers and evaluators in the field, as well as officials from NSF and the Department of Education.
4. recent issues of the Journal of Research in Science Teaching, Science Education, and School Science and Mathematics for articles that may not yet have been entered in the ERIC system.

The candidate studies identified through this procedure were obtained through a lengthy interlibrary loan and ERIC document ordering process except for some that were not available.

Studies of student achievement were selected for inclusion if they met the following criteria:

1. grades K-12.
2. conducted within the United States.
3. published 1950 or later.
4. exclude dissertations.[3]
5. NSF must have funded all or part of the institute.
6. An experimental group must include a teacher institute or some form of in-service science or mathematics-related training. ("In-service" includes any training after initial certification.)
7. Control or comparison group must be included.
8. Student academic achievement must be an outcome variable.

9. If the institute involved study of a new mathematics or science curriculum (as many institutes did, particularly in the later years of the program), there must have been some design or analytic procedure to attempt to separate effects of training from effects of introducing the new curriculum into the participating teachers' classes.

While this is an extensive list of criteria, it is an appropriate one, given the information we need on the effectiveness of teacher upgrading. We found two studies showing gains in student achievement, but with no means of comparison there was no reason either to consider the gains anything beyond normal expected learning or to attribute the gains to institute participation by the students' teachers. We found four studies that approached our criteria. Two were funded by other agencies (National Institute of Education and the Environmental Protection Agency). The third involved unspecified training of four teachers in a new mathematics curriculum (SMSG), and the fourth concerned a program operated by a university and several school districts involving the training of local resource leaders who subsequently designed a variety of local training programs. These four studies represent an unusual assortment. We are uncertain how similar they were to activities funded by NSF. Applying our criteria, we found only the one study reported by Victor Willson and Antoine Garibaldi (see appendix II).

NOTES

[1] See Marilyn N. Suydam and Alan Osborne, The Status of Pre-College Science, Mathematics, and Social Science Education: 1955-1975, vol. 2, Mathematics Education (Columbus, Ohio: Center for Science and Mathematics Education, 1977), ch. 3; Stanley L. Helgeson, "Impact of the National Science Foundation Teacher Institute Program," University of Minnesota, Minneapolis, 1974; Hugh Munby, "Thirty Studies Involving the 'Scientific Attitude Inventory': What Confidence Can We Have in This Instrument?" Journal of Research in Science Teaching, 20:2 (1983), 141-62.

[2] Helgeson; Suydam and Osborne; Stanley Helgeson et al., The Status of Pre-College Science, Mathematics and Science Education: 1955-1975, vol. 1, Science Education (Columbus, Ohio: Center for Science and Mathematics Education, 1977), ch. 3.

[3] The use of dissertations was not practical given staffing and time limits. The senior author of a major series of meta-analyses in science education concluded that dissertations tend to have smaller average effect sizes than journal articles. However, the differences are small enough that "all indications are that a complete or random sampling of studies is not critical." Ronald D. Anderson, "A Consolidation and Appraisal of Science Meta-Analyses," Journal of Research in Science Teaching, 20:5 (1983), 499 and 507.

NOTES ON THE STUDY DESIGN, METHODOLOGY, AND RESULTS OF THE WILLSON AND GARIBALDI RESEARCH

The Willson and Garibaldi research examined the achievement of students whose teachers had high participation in NSF institutes (3-14 institutes attended), medium participation (1-2 institutes), and low participation (no institutes).[1] Principals of sampled schools randomly selected one science or mathematics teacher who in turn was asked to complete a questionnaire, take the applicable National Teacher Examination, and select one class at random for testing. Science students took the Test of Achievement in Science (consisting of 40 items selected from the National Assessment of Educational Progress) while mathematics students took the Mathematics Achievement Test (composed of 40 items from the National Longitudinal Study of Mathematical Abilities). Two forms were developed for each subject area, one for 8th and one for 11th graders. A total of 346 teachers and classes participated in science and 211 in mathematics. Science classes were from schools sampled in Wyoming, South Dakota, and Mississippi regions while mathematics classes were in California and Indiana regions.[2] Analysis of covariance results show NSF participation was a significant factor in high school science and mathematics achievement. Region was also a significant factor in science achievement. A covariate--teacher achievement test score--was included because the teachers attending NSF institutes were believed to be more academically able, as we discussed in chapter 3. In the present context, including teacher achievement as a covariate could have removed effects of additional learning gained at the institutes. The covariate was nonsignificant in all cases, suggesting that the teachers' knowledge of science or mathematics was not related to their students' achievement. NSF participation was not significant for 8th-grade student achievement in either science or mathematics.

This study does suggest positive effects of NSF institutes . the high school level for both science and mathematics achievement. The results do not seem attributable to higher ability of the classes taught by NSF institute participants. Contingency tables of amount of NSF institute participation by teacher ratings of the ability of the sampled classes were prepared for each of the four groups (two grade levels and two subjects). There were no significant associations, indicating that teachers with more NSF institute experience were not systematically assigned to more able classes.

Although this study meets our screening criteria presented earlier in this section, it still has weaknesses due to the nonexperimental nature of the design used. Self-selection is one major threat to the validity of the study. It is possible that a professionalism or drive for self-improvement led teachers to apply to attend NSF institutes and it was that initiative rather than any effect of the institutes that had some effect on student achievement. In a similar fashion, it is possible that schools with more teachers applying for NSF institutes are more achievement oriented, more demanding in their recruitment of teachers, and in other ways produce higher achieving students.

We noted that the authors found no association between institute attendance and teachers rating of the ability group of the class selected for testing. A study design involving pre- and post-tests would be a much stronger control over possible differences in initial ability of the students of institute attenders compared with nonattenders. The authors note that if NSF had followed an experimental stategy, a stronger analysis than this post hoc approach would have been possible. The approach actually used is also open to mortality problems. If teachers receiving training had more subsequent opportunities, which over a period of years led the better teachers to leave the classrooms or to migrate to better paying jobs in more urban areas, a subsequent examination of teacher effects could be said to underestimate training effects. It is certainly true that this sample was rural less than 20 percent of schools were in cities of 50,000 population or more. Finally, we note that there was no on-site data quality control. Sampling of teachers, classes, and students was all done by school staff with only instructions from the researchers. The teacher tests were self-administered and school personnel gave the student tests. This is not to say that this study was poorly done. It was the best we found but still has significant limitations.

NOTES

[1] Victor L. Willson and Antoine M. Garibaldi, "The Association Between Teacher Participation in NSF Institutes and Student Achievement," Journal of Research in Science Teaching, 13:5 (1976), 431-39, and "The Effect of Teacher Participation in NSF Institutes Upon Student Achievement," revised, University of Minnesota, Minneapolis, September 30, 1974.

[2] Regions were not contiguous with states. For example, Denver was part of the Wyoming region.

AGENCY COMMENTS AND OUR RESPONSE

All four agencies responded to our request for comment on a draft of this report: NSF, the Department of Education, the Office of Science and Technology Policy, and the Office of Management and Budget. We first address the major comments that appeared in some form in two or more agency replies. We then deal with the additional comments. The letters are reprinted at the end of this appendix.

MAJOR COMMENTS

The agencies generally characterized the report as useful and addressed to issues of major importance. There are two main areas of comment.

First. All agencies expressed some concern about our finding little evidence that institute types of programs for science and mathematics teachers have produced improved student achievement. The Department of Education believes that such programs "can improve teaching effectiveness" and anticipates "a substantial requirement for new subject-matter mastery for most mathematics and science teachers." The Office of Management and Budget and NSF question the different criteria used to measure the effectiveness of training for upgrading teachers and retraining programs. NSF is concerned that our report may be counterproductive to the efforts of other national reports calling "for enhancing the attractiveness of the teaching profession and for increasing the educational standards for teachers, especially their subject matter knowledge." The Office of Science and Technology Policy feels that we have a "clear bias against upgrading the quality of existing mathematics and science teachers."

Our response. We are not arguing that efforts to upgrade existing mathematics and science teachers should stop. We assume that individual science and mathematics teachers will take subject matter courses and that many will be assisted financially by their LEA's and other sources. Similarly, we wish to advance rather than oppose efforts to improve science and mathematics education in the public schools. But many remedies have been suggested for improving mathematics and science education. One major task facing education policymakers is to identify the remedies in which they will invest time and resources, the remedies in which they will make little or no investment and the remedies in which they will invest on a pilot basis. Our analysis suggests that programs geared to upgrading existing science and mathematics teachers have not been shown to produce results in terms of improved student achievement. This is not a "bias" but the results of our evaluation.

Only two factual arguments are raised against our position.
1. NSF argues that we should have included the results of a

meta-analysis of studies of science teacher characteristics as related to student outcomes. Only two of the studies included in that meta-analysis were of academic institutes, however. They were in the group of studies we considered for selection (see appendix I). Also, we did not report on studies linking the amount of teacher preparation in science to student outcomes, which is the major finding of that research cited by NSF. Rather, we looked at studies linking teacher knowledge--whether acquired through ability, coursework, self-teaching--and student academic achievement. In any event, the correlations found in the study NSF cites were very small; the correlations of academic institute training with student achievement were less than half of the correlations for variables such as "masculinity." As the author notes, "The most striking overall characteristic of the results of this meta-analysis is the pattern of low correlations across the large number of variables involved."[1] The NSF argument is inconsistent in the sense that NSF notes "the limitations of the correlational studies," which we cite. But the study NSF wanted us to report is a meta-analysis, which is also a correlational method of analysis. NSF admits that the effect sizes in the research they cite are small but feels that is "what is to be expected" in such settings. Thus, in the final analysis, NSF agrees with us that these teacher characteristics have not been shown to have a moderate or reliable effect upon student outcomes.

2. The argument is raised by NSF and the Office of Management and Budget that we use different criteria, relying upon student achievement gains in assessing teacher upgrading but upon the completion of certification by teachers in assessing retraining programs. Since upgrading programs are for addressing teacher quality problems, while retraining programs are for the purpose of solving the shortage or quantity problems, we believe that different criteria are both appropriate and necessary. The shortage of mathematics and science teachers is defined as the absence of teachers certified in these fields. Our research suggests that retraining programs offer early evidence of success in remedying this shortage. The comparative quality of teachers graduating from retraining programs compared with traditional study is an interesting question but one that extends beyond the question of remedying teacher shortages and into teacher quality concerns. We discuss these issues in some detail in chapters 4 and 6.

NSF and the Office of Management and Budget both seem to be suggesting that teacher upgrading may help increase teacher retention or make the profession more attractive to others. We respond that efforts such as the NSF program for Presidential Awards for Teaching Excellence in Science and Mathematics as well as the Honors Workshop for Teachers of Science and Mathematics seem to be more directly linked to objectives of enhancing the attractiveness of the teaching profession. (We have not studied the actual effects of these programs but refer here to the intended direct effects of programs.) Also see our discussion of the pending science and mathematics legislation and other remedies such as increased pay for teachers (chapter 2).

In conclusion, the few facts presented by the agencies do not give us reason to alter our findings.

Second. Three agencies agree on the need for improved evaluation and statistics (see chapters 5 and 6). The Office of Management and Budget says the federal government "should take steps to ensure effective ongoing evaluation" in mathematics and science education. The agency agrees that there is now a "lack of information available to shape fully effective Federal programs for improving mathematics and science education." NSF concurs that there is a "need for reliable and regularly collected data on the supply and demand of science and mathematics teachers and we also recognize the need for the National Science Foundation to improve its program evaluation effort." The Department of Education agrees that a systematic study that examines all of the relevant factors in teacher shortages is necessary. The Department of Education favors data-gathering when "timely and economical, and when suitable methodology exists" but believes that no "suitable methodology presently exists that can be applied to Figure 1."

Our response. We are pleased at the level of agreement and hope that the agencies will begin establishing priorities for evaluation and other data collection. Figure 1 is intended to conceptualize the factors that may influence teacher quality and subsequent student achievement. Its purpose is to organize the relevant variables and help to identify data gaps and future evaluation priorities. We are not proposing a comprehensive study of all factors included in figure 1.

ADDITIONAL COMMENTS

The Department of Education

First. The Department of Education believes that there is evidence of current mathematics and science teacher shortages sufficient to justify federal action. The department characterizes our report as containing "no contradictory evidence, nor does it make an effort to structure a definition of what constitutes a shortage that merits federal action."

We do not take a position on whether or not federal action in mathematics and science education is justified. What we do argue--and what the department fails to rebut--is that data adequate to determine whether or not there is a new nationwide shortage of mathematics and physical science teachers do not exist.

Second. The Department of Education also holds

> "a different view from that expressed in the report on the contrary effects on teacher shortages of increased graduation requirements and declining enrollments, and believe teacher shortages may increase."

We argue that increased graduation requirements would seem to lead to increased teacher shortages although various factors may negate such additional shortages (chapter 2). We note that one contrary factor could be continued declines in high school enrollments, as projected by the Department of Education.

National Science Foundation

First. NSF objects to our treatment of "process-product" research characterizing that research as resting on "tenuous evidence" and as "irrelevant to the immediate problem of high school science and mathematics."

We ourselves note these limitations of process-product research in the text but cite the work because applying the process-product methodology to exploring effective teaching in secondary school mathematics and science classes could be a valuable contribution. We also note other areas of recent research. See chapters 3 and 6.

Second. NSF also states that our report is incomplete in that it ignores "practices in some projects and programs that represented significant departures from early 'institute' practices."

We are not clear what material NSF would like added. This report is not intended to be a comprehensive evaluation of all NSF teacher education activities.

Office of Science and Technology Policy

The agency finds with regard to our finding on upgrading teachers that what "starts as a qualified statement in chapter 3 becomes stronger in succeeding chapters and ends up as an assertion in the digest."

The digest conclusion--"GAO does not find evidence that training programs to upgrade existing mathematics and science teachers will produce results in terms of improved student achievement"--deals with the lack of evidence on program effectiveness. The central conclusion in chapters 3 and 6 considers the implications of this lack of evidence, namely that "programs geared at upgrading existing mathematics and science teachers may not produce results in terms of improved student achievement."

Office of Management and Budget

The agency observes that the need for additional science and mathematics teachers varies from district to district and that the most appropriate methods for overcoming shortages differ across districts.

We made similar arguments in chapters 2 and 4.

NOTES

[1] Cynthia Ann Druva and Ronald D. Anderson, "Science Teacher Characteristics by Teacher Behavior and by Student Outcome: A Meta-Analysis of Research," Journal of Research in Science Teaching, 20:5 (1983), p. 478.

UNITED STATES DEPARTMENT OF EDUCATION
WASHINGTON D C 20202

ASSISTANT SECRETARY
FOR EDUCATIONAL RESEARCH AND IMPROVEMENT

JAN [illegible]

Mr. Richard L. Fogel
Director
Human Resources Division
United States General Accounting Office
Washington, D.C. 20548

Dear Mr. Fogel:

On behalf of the Secretary of Education, I wish to thank you for the opportunity to review and comment upon the proposed GAO report, "New Directions for Federal Programs to Aid Mathematics and Science Teaching." It has relevance for various Departmental activities and initiatives, and it contains much useful information. We find, however, that we are unable to concur in two of the report's major findings, and must qualify our concurrence in a third. Our summary response is organized along these findings.

(1) We believe well designed programs to upgrade existing secondary school mathematics and science teachers can improve teaching effectiveness. Such programs should emphasize a suitable mix of subject-matter mastery, and pedagogical-skills and classroom-management mastery as may be required by the particular characteristics of the program's teacher participants. Given present changes in the nature of the economy and new conceptualizations and discoveries in the fields of mathematics and science, we anticipate a substantial requirement for new subject-matter mastery for most mathematics and science teachers. This view is broadly held in the education and science education communities, and is included in the recommendations of both the National Commission on Excellence in Education and the National Science Board's Commission on Precollege Education in Mathematics, Science and Technology. Our reading of the proposed GAO report is that it contains some evidence in support of this view and little or none to contradict it. If declining test scores are a current policy concern, we find upgrading as we define it here to be an appropriate national policy.

(2) We believe sufficient evidence of current teacher shortages exists to justify federal action. Among this evidence are the strong efforts presently being made by States and localities that involve substantial expenditures in retraining programs to correct the deficit. The proposed GAO report contains no contradictory evidence, nor does it make an

effort to structure a definition of what constitutes a shortage that merits federal action. The Administration's proposal to assist the States in correcting the current deficit is contained in the Science and Mathematics Teacher Development Act of 1983 (H.R. 1324 and S. 706). We also hold a different view from that expressed in the report on the contrary effects on teacher shortages of increased graduation requirements and declining enrollment, and believe teacher shortages may increase. A systematic study that examines all of the relevant factors is necessary to assist in better defining the precise nature, extent and especially the need for long term action.

(3) While we believe more data, better data and more and better program evaluations are generally desirable, we observe that they are not without cost, nor -- in the historical record -- without limit in their utility to policy-makers. We do favor data-gathering, including statistical data-gathering, and program evaluations when these are timely and economical, and when suitable methodology exists. For example, we are unaware that suitable methodology presently exists that can be applied
* to Figure 1, page 5-6, of the report in a way that can be expected to provide unambiguous guidance for policy makers.

If any clarification of these comments is required, I may be reached at 254-8251.

Sincerely,

Donald J Senese

Donald J. Senese

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*GAO note: page 60.

NATIONAL SCIENCE FOUNDATION
WASHINGTON D C 20550

OFFICE OF THE
DIRECTOR

January 13, 1984

Mr. J. Dexter Peach
Director, Resources, Community, and
  Economic Development Division
United States General Accounting Office
Washington, D.C. 20548

Dear Mr. Peach:

Thank you for your letter of December 15, 1983, enclosing an advance draft of the proposed report "New Directions for Federal Programs to Aid Mathematics and Science Teaching." We find the issues addressed to be of major importance and appreciate having the opportunity to comment.

We find that we are in substantial agreement with some of the observations and recommendations made in the report. Specifically, we agree with the position stressing the need for reliable and regularly collected data on the supply and demand of science and mathematics teachers and we also recognize the need for the National Science Foundation to improve its program evaluation effort.

Yet, we find other positions -- indeed, the main positions -- unfortunate and actually counterproductive to the national effort to improve science and mathematics education. Several national reports call for enhancing the attractiveness of the teaching profession and for increasing the educational standards for teachers, especially their subject matter knowledge, as essential to improving the effectiveness of teaching and the participation and achievement of students in science and mathematics. The position taken in the report undermines the momentum that has been building at the Federal, State and local levels.

I have enclosed additional comments made by members of the Foundation's staff. In view of the points raised, I believe the present draft of the report is not only confusing, but may lead in the wrong direction with regard to public policy formulation.

Sincerely,

Edward Knapp

Edward A. Knapp
Director

Enclosure

NSF Staff Comments on the GAO Report, "New Directions for Federal Programs to Aid Mathematics and Science Teaching"

The report's position that "programs geared at upgrading existing mathematics and science teachers are not likely to produce results in terms of improved student achievement. . ." -- even as qualified within the text -- runs counter to the national consensus, and the limited data presented within the report do not warrant such a sweeping conclusion.

*Furthermore, in section 3, the conclusions state that general research "failed to show any consistent relationship between the extent of teachers' knowledge and subsequent student learning. . . [and] the studies of secondary school science and math learning in the 1960's and 1970's failed to show any straightforward relationship between teachers' knowledge and subsequent student learning." These conclusions may be unwarranted and based on an incomplete consideration of recently published research on this matter. For example, an extensive analysis of 65 studies of science teacher characteristics as related to teacher behavior and student outcomes (see the Journal of Research in Science Teaching, Volume 20 [1983], pp. 467-479) concludes:

- "Student outcomes are positively associated with the preparation of the teacher, especially science training . . .;
- ". . . an intellectual orientation on the part of teachers is positively related to cognitive student outcomes. . .; [and]
- "The relationship between teachers' training in science and cognitive student outcome is progressively higher in higher level science courses."

These authors use the powerful quantitative technique of meta-analysis to compare effect size across these 65 studies (75% of which were performed between 1966 and 1975). They point out that the effect sizes are relatively small but what is to be expected in such complex multivariate settings. Consequently, the conclusions as stated in the draft report are misleading.

Given the limitations of the correlational studies cited in the GAO report and considering the complexity of the multivariate system being considered, we believe the GAO position on teachers' knowledge to be unwarranted and to jeopardize the overall policy goals (Federal, State and local) for improving teacher subject matter competence as a means to improving the education of students.

*GAO note: chapter 3.

It also seems to us that holding out "process-product" research results with elementary school teachers as offering the means of improving student *achievement (pp. 3-23 to 3-26) not only rests on tenuous evidence but is irrelevant to the immediate problem of high school science and mathematics, which is of central concern in the report. As a result, its inclusion may be misleading.

Other aspects of the report are also troubling to us, and we list a few without going into detail.

- The report uses criteria inconsistently. For example, teacher upgrading programs are discussed in terms of student achievement, but the retraining programs for teachers in other fields to become mathematics and science teachers are judged by the number of participants immediately or eventually certified.
- The report is incomplete on NSF teacher education programs in ignoring practices in some projects and programs that represented significant departures from early "institute" practices.

*GAO note: Pages 34-36.

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20500

January 18, 1984

Dear Mr. Peach:

This is in response to your recent letter to Dr. Keyworth transmitting the draft report "New Directions for Federal Programs to Aid Mathematics and Science Teaching" for our review and comment.

As a general comment, the report is longer than necessary to make its points. Only the most dedicated readers are likely to sift through all the detail in order to verify the statements made in the digest.

A major flaw of the report is its clear bias against upgrading the quality of existing mathematics and science teachers. What starts as a qualified statement in Chapter 3 becomes stronger in succeeding chapters and ends up as an assertion in the digest. The evidence to support this assertion is no stronger than the counter evidence which is noted but suppressed. A superficial reading of the report is not likely to uncover this point.

Given these difficulties with logic and objectivity, the report in its present form will be misleading if used for policy formulation.

Sincerely,

James G. Ling

James G. Ling
Assistant Director

Mr. J. Dexter Peach
Director
Resources, Community, and
  Economic Development Division
U.S. General Accounting Office
Washington, D.C. 20548

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

JAN 2 0 1984

Mr. William J. Anderson
Director, General Government
Division
United States General
Accounting Office
Washington, D.C. 20548

Dear Mr. Anderson:

Thank you for giving us an opportunity to comment on your draft report, "New Directions for Federal Programs to Aid Mathematics and Science Teaching."

The report provides very useful background on the National Science Foundation's previous in-service teacher training programs and on a select sample of teacher retraining programs now in operation across the country. While we agree with many of the report's observations about the advantages and disadvantages of in-service training and retraining, we remain reluctant to draw a conclusion that either of these approaches is superior.

Your report assesses the relative effectiveness of these two strategies using different standards. It uses student achievement gains to measure the effectiveness of in-service training programs like those administered by NSF in prior years. The report uses an unrelated measure, the increase in certified math and science teachers, to evaluate the teacher retraining approach. Of equal interest would be: (1) how in-service training programs influence teacher supply (either by increasing teacher retention or making the profession more attractive to others); and (2) the effectiveness of retrained teachers in raising student achievement in science and math.

The findings in Chapter 5 of your report support our general belief that there is a lack of information available to shape fully effective Federal programs for improving mathematics and science education. The resource levels proposed by this Administration for science and mathematics education programs reflect the judgment that the Federal Government should proceed cautiously in making investments in pre-college mathematics and science education. It should also take steps to ensure effective ongoing evaluation.

The observations in your report are quite consistent with this Administration's view that:

- the primary responsibility for generating resources and designing programs to meet local education needs should remain at the State and school district level.

- the Federal government can be most effective as a catalyst in this area and should encourage more direct action by State and local governments and businesses.

As your report makes clear, the need for additional science and mathematics teachers varies considerably from district to district and is apparently non-existent for some. Similarly, the most appropriate methods for overcoming teacher shortages differ across districts; the Houston example, while effective, is clearly not appropriate for many districts where collective bargaining agreements would interfere.

We hope you will consider these comments in developing your final report. Thank you again for the opportunity to respond.

Sincerely,

Joseph R. Wright, Jr.
Deputy Director

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