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ABSTRACT

This report provides an analysis of issues and recommendations for further implementation of the National Education Goals and the America 2000 National Education Strategy related to education in mathematics, science, engineering, and technology. This report considers teachers and teaching at every level. The report focuses on the need to build a stronger foundation for understanding mathematics and science throughout society by placing special emphasis on the improvement of elementary and secondary education in these fields for all children. The titles of the chapters are: (1) "Background"; (2) "Education in Science and Mathematics: Meeting the National Education Goals"; (3) "Nurturing Special Aptitudes: Developing Superb Scientists and Engineers"; (4) "Who Shall Lead the Way? Teachers of Science, Mathematics, Engineering, and Technology"; (5) "Learning Through Research"; and (6) "Recommendations." (PR)

LEARNING TO MEET THE SCIENCE AND TECHNOLOGY CHALLENGE

The Council provides private sector advice to the President in matters of national importance involving science and technology. The Council responds to requests from the President and aggressively maintains a general watch on developments to be in a position to raise issues, opportunities, and concerns to the President. The issues that the Council addresses normally affect not only the private sector but cut across Federal Department and Agency boundaries. In addition to being fully responsive to the President, the Council considers requests made by the Vice President and others within the Executive Office of the President.

Although the boundaries are not clear-cut, the Council's advisory work falls broadly into three categories: (1) emerging science and technology issues; (2) policy for science and technology as well as science and technology for policy; and (3) structural and strategic management policies within the Federal government as well as policies in non-governmental organizations.

The Council is currently composed of 13 members, including the Chairman, who provide perspectives from academia, industry, private foundations and research institutes.

LEARNING TO MEET THE SCIENCE AND TECHNOLOGY CHALLENGE

A REPORT PREPARED BY THE
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

DECEMBER 1992

THE PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

THE WHITE HOUSE

WASHINGTON

November 16, 1992

Dear Mr. President:

Your leadership has stimulated the nation to undertake unprecedented educational reform. This leadership has also mobilized the talent and resources of the Federal government to support this reform effort through the Federal Coordinating Council for Science, Engineering, and Technology. It is a pleasure to transmit to you, on behalf of your Council of Advisors on Science and Technology, a report that provides an analysis of issues and recommendations for further implementation of the National Education Goals and the America 2000 National Education Strategy related to education in mathematics, science, engineering, and technology. The report is entitled *LEARNING to Meet the Science and Technology Challenge.*

The President's Council of Advisors on Science and Technology (PCAST) believe that the national reform effort is beginning to produce a consensus for a process that: (1) continues to build support for achieving the National Education Goals; (2) sets national education standards that help identify the common core of knowledge and competencies that are expected of all children; (3) develops a national system of assessments designed to measure performance and fulfillment of the standards; and (4) challenges every teacher in every school to develop responses to the heightened demands for educating American children.

This report considers teachers and teaching at every level. We focused on the need to build a stronger foundation for understanding mathematics and science throughout our society by placing special emphasis on the improvement of elementary and secondary education in these fields for all of our children.

Since there is evidence that our educational system often fails to encourage outstanding performance, the Council particularly focused on the need for nurturing special aptitudes for science and technology. We found that aptitudes in scientific and technological fields are often unrecognized or discouraged, particularly among girls and the children of disadvantaged groups. Specific strategies are recommended for nurturing special aptitudes in order that society may fully benefit from the contributions of superb scientists and engineers.

Finally, the report notes new ways to engage young minds in modes of thought that are needed in science, mathematics, engineering, and technology. There are several approaches to teaching and learning that give expression to our theme of *learning through research.*

The PCAST members would be pleased to discuss any part of this report with you that may be of particular interest. With your permission and following your review, I propose that this report be made public as a contribution to the continuing deliberations on reforming education in mathematics, science, engineering, and technology.

The Bush Administration has provided very strong support and leadership for science and technology, including science and technology education. The recommendations contained in this report are designed to further strengthen this vital investment in our nation's future. We believe that continued commitment and a sustained effort are required if educational reform in the nation is to be fully realized.

Sincerely yours,

D. Allan Bromley
The Assistant to the President
for
Science and Technology
and
Chairman
President's Council of Advisors on Science and Technology

The President
The White House
Washington, D.C. 20500

Enclosure

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

November 11, 1992

Dear Dr. Bromley:

It is with pleasure that I submit to you the report, *LEARNING to Meet the Science and Technology Challenge,* on behalf of the panel I co-chaired with Charles Drake for the President's Council of Advisors on Science and Technology (PCAST).

The leadership of the President has stimulated our Nation to undertake unprecedented initiatives toward reform of basic education. This leadership has also mobilized, through the Federal Coordinating Council for Science, Engineering, and Technology, the talent and resources of the Federal government in support of this reform effort. Our report provides suggestions and recommendations for further implementation of the National Education Goals and the America 2000 strategy.

We take the view that the security and prosperity of the Nation require policies that ensure higher levels of scientific and technological knowledge and skill for all Americans, which is why we have chosen the title we have for this report. The dramatic actions underway must be sustained for several more years in order to assure that needed changes occur and become permanent.

Sincerely yours,

Peter Likins

Peter Likins
Co-Chairman of PCAST Panel
on Education and Human Resources

Enclosure

The Honorable D. Allan Bromley
Assistant to the President for
Science & Technology
Executive Office of the President
Washington, DC

THE PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY

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CONTENTS

PREFACE

The reader is forewarned: Do not search within these pages for a painless, magical elixir to cure the ills of our learning systems in America. The members of the President's Council of Advisors on Science and Technology are persuaded that the learning challenge in America requires a sustained commitment to hard work on many fronts, so we have prescribed a balanced diet and a strict regimen of disciplined exercise. Our objective has been to deal with a very complex set of problems in a realistic and useful way. We hope fervently that we have succeeded.

EXECUTIVE SUMMARY

The nation that dramatically and boldly led the world into the age of technology is failing to provide its own children with the intellectual tools needed for the 21st century.

National Science Board Commission on
Precollege Education in Mathematics,
Science, and Technology (1983)

THE CHALLENGE

The emergence of the United States of America among the leading nations of the world in the 20th century derives substantially from our pre-eminence in technology and industrial production in the first half of the century. Our continuing strength is based substantially on our leadership in both science and technology in the decades following World War II. It is highly likely that science and technology will become even more significant in the 21st century in their influence on our physical and economic security, on our standard of living, and on the quality of life of people throughout the world.

As we approach the beginning of the 21st century, it is becoming apparent that our nation's leadership in science and technology is not assured. In many critical areas of techn logy we are clearly no longer the best in the world. Thus we face in this country a *science and technology challenge.* This is not the *only* challenge that must be met for the security and prosperity of this nation, but unless we meet the science and technology challenge security and prosperity will suffer.

Confronting the complex issues associated with the science and technology challenge will require more dramatic and more sustained actions on the part of the President and the federal government over the next decade than at any time in the past twenty-five years. New federal initiatives must focus on the deployment of our best scientific and technical resources to address the National Education Goals. On the one hand, we need to identify and develop our most promising students, those who will ultimately lead this nation's science and technology efforts. At the same time, we need to promote policies that ensure higher levels of scientific and technological knowledge and skill for all Americans.

The President's Council of Advisors on Science and Technology (PCAST) applauds the work of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) in integrating the broad array of federal policies and programs that support science and engineering education. We urge expanded commitment to the FCCSET initiatives in science and engineering education and provide recommendations for specific actions in the body of this report.

Competitive advantage in science and technology depends increasingly on human capability. Of course, scientists, engineers, and technologists require excellent facilities to do work that meets the standards of global competition. But the most critical factor in meeting the science and technology challenge is the development throughout society of people who can learn how to work effectively in an increasingly technical environment. That's why this report is called "LEARNING to Meet the Science and Technology Challenge."

We know that *learning* has many aspects, among them teaching, research, and other modes of discovery. We also recognize that learning about science and technology is important for everyone: factory workers, office staff, corporate managers, parents, physicians, lawyers, and accountants in addition to teachers, scientists, and engineers. Stimulating learning about science, mathematics, engineering, and technology at all levels and throughout society is *necessary* (but not sufficient) for the health of our economy and the welfare of our people.

Our task begins with our youngest children, or even with prenatal care, but it doesn't end with the adolescent years. Success requires superb teachers, scientists, and engineers educated and re-educated throughout their lives. And the engines of industry are driven by workers who require continuing education to keep up with the changing demands of their jobs. Unless we face the needs of the *entire* population, we will fail to meet the science and technology challenge.

Federal relationships with research intensive universities are particularly complex, and PCAST has undertaken a separate, major study of this subject. These issues are addressed only tangentially in the present report.

THE NATIONAL EDUCATION GOALS

Our society is approaching consensus regarding the steps that will lead to necessary improvements in basic (elementary and secondary) education. This process is as follows:

- Establish National Education Goals.

- Establish National Education Standards defining appropriate educational progress in each of the critical fields, including science and mathematics.

- Establish a national system of performance assessment instruments and procedures (but not a federally mandated test).

- Develop local and regional strategies for meeting the National Education Standards using approved methods of assessment (but not a federally mandated national curriculum).

- Develop statistically valid instruments (such as those of the National Assessment of Educational Progress programs) to define a single federally sanctioned statistical measurement of the comparative progress of groups of students and teachers (but not of individuals).

The first step has been taken with the adoption in 1990 of the National Education Goals developed by the President and the nation's Governors. The remaining steps in this process are well underway through the implementation of the America 2000 strategy. Debate will continue, but we strongly recommend accepting this process as a baseline policy and getting on with the difficult job of implementation. The year 2000 will soon be upon us, and our task is just beginning.

Unless the entire system of basic education is reconstructed in quite fundamental ways, with an emphasis on standards within a range of options, it will not be possible to achieve our goals in mathematics and science education.

General Recommendations

Our entire system of education has not adapted adequately to the demands of a changing world, with consequences that are now most evident in elementary and secondary education. It is absolutely essential that the required adaptation be accelerated throughout the system, or it will not be possible to restore and preserve our global leadership in living standards for our people.

As we strive to meet the science and technology challenge of this nation, we must recognize immediately that we cannot succeed without effective and dedicated teachers at all levels, from grade school to graduate school and beyond, leading the way through lifetime learning. Moreover, all teachers must have the goal of motivating every student by means of creative curricula and innovative engagements with good science and technology.

We must recognize at the same time that strengthening the quality of teachers is but one aspect of our challenge, because learning is not limited to formal schooling. We must accept responsibility in all sectors of our society for improving education, forging partnerships that include families, churches and community groups, business and industry, labor, and government at all levels to join with schools, colleges, and universities in a concerted effort to rebuild the American dream on the foundation of learning.

As a general principle, adaptation and change are accelerated by the availability of alternative choices in a creative atmosphere. We must preserve and exploit more effectively the variety of options now available to Americans. However, we also need to find ways to diversify our educational strategies and encourage more options. In postsecondary education, we must enhance the opportunities for those seeking to become technicians or technologists.

If there is a single theme that should guide all of the necessary educational reforms, it is this: We must strive to meet the developmental needs of each individual in our society so as to derive the maximum benefit from the potential capabilities of all members of our society. In short, we must get from everyone their very best. The implications of this theme are pervasive; grade school learning experiences must be adapted to the child, and college courses must be shaped to the varying needs and capabilities of the students enrolled. We must recognize that technicians and technologists are important members of a productive society and develop the needed skills where aptitudes and interests permit. We cannot afford to waste human capability, because in the modern world human resources are the primary assets of any society.

We are deeply concerned about the lost potential represented by undeveloped talent for science, mathematics, engineering, and technology in America. The losses are probably most critical for those sectors of our population that lack a tradition of participation in these fields. If our society is to derive full advantage of the talent of its people in science, mathematics, engineering, and technology, there must be special emphasis on the development of capacity among females and those growing populations now referred to as minorities. It is important to recognize that our concern for undeveloped potential in these groups is not driven by any quantitative assumptions about the demand for professionals, but rather by the knowledge that our society will benefit by increasing the depth and breadth of understanding of science and technology throughout the population.

A major problem that must be addressed is the need to increase educational productivity so as to maximally improve our educational performance within resource constraints. Significant reallocations of resources may be necessary. Productivity improvements may in part be achieved by better use of technology. Electronic networking to share teaching and learning resources provides an example.

ADVICE TO THE FEDERAL GOVERNMENT

PCAST is the President's Council of Advisors on Science and Technology, and we recognize a special obligation to advise the President of the United States and the agencies of the executive branch of our government. The nature of our democracy requires that such advice be directed to the United States Congress as well.

The fundamental message to the federal government is the same advice offered to all other partners in the educational enterprise, as noted above: Advance the National Education Goals; accelerate the adaptation of the entire educational system to changing global requirements, including more educational options and choices; focus on the development of individuals; nurture especially the interests and talents of females and minorities in science and mathematics; emphasize the development of teachers in fields relating to science and technology; and facilitate the formation of community partnerships committed to education as a key priority of our society. All of these objectives require the support and encouragement of the federal government, but none can be accomplished by the government alone. In some areas, such as educational technology, capital investments by the federal government may be essential to progress. In other areas, such as community partnership formation, the role of the federal government may be limited to encouragement. In every case, however, there is a role.

There are specific federal programs that should be initiated or expanded in an effort to recognize and encourage excellent performance in science and mathematics by young people with undeveloped potential in these fields. Three examples of existing programs that warrant expansion are the *Young Scholars Program* and the *Research Experiences for Undergraduates Program* of the National Science Foundation and the *Javits Gifted and Talented Education Program* of the Department of Education. We recommend in addition a major initiative to establish summer laboratory schools at NASA and DOE facilities for students and teachers in grades seven through twelve. Furthermore, technical training programs developed for military service personnel should be adapted wherever possible in the public sector.

We note some disturbing trends in post-secondary education in science, mathematics, engineering, and technology and recommend renewed attention to the more advanced programs for education and research in these fields. Faculty priorities must focus still more on students, with emphasis on teaching and on research as a learning experience. Because federal research funds provide powerful incentives that shape faculty values, the federal government can influence faculty priorities by giving more attention to curriculum development, instructional innovation, and effective teaching. Recognition of teaching excellence, instructional scholarship, and public service can also influence the value systems of our colleges and universities.

Fellowships, traineeships, and loan forgiveness programs for graduate students should be instruments of federal policy designed to encourage U.S. citizens and permanent residents to pursue advanced education in critical fields, such as science, mathematics, engineering and education in related areas. Such support may extend to programs for retraining of current teachers, especially to address the need for mathematics and science specialists in elementary education.

Finally, it should be recognized by the federal government that the escalating costs of education must ultimately be controlled, in part, by increases in educational productivity, and federal sponsorship of initiatives to improve productivity should receive high priority. One principal strategy for productivity improvement relies upon applications of instructional technology that may require substantial initial investments. A federal initiative that stimulates the development of educational technologies or opens new pedagogies may be important to progress in this area.

ADVICE TO THE PRESIDENT

The President is advised to make every effort to maintain the leadership initiative established in this area, and to reinforce the public's understanding of the powerful linkage between the prosperity of a nation and the education of its citizenry. Goal #5 of the six National Education Goals says it well:

> By the year 2000, every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship.

We would have the President take note of the critical significance of basic education in mathematics and science to this goal, and recognize too that the achievement of world class standards in elementary and high school mathematics and science is not enough for a nation to be competitive in the global economy. Improvement is required also in post-secondary education in these fields right through graduate study, as well as in continuing education in engineering, science, and mathematics, if our nation is to meet the global competition for ideas, products, and services.

The Council urges the President to expand his commitment to the FCCSET initiatives in science and engineering education, including programs to motivate and reward excellence in teaching at all levels and in both formal and informal settings.

Finally, it is imperative that priorities in the President's 1994 budget proposal and subsequent budget and legislative proposals match actions and words. We recognize the magnitude of this task in an era when deficit reduction requires very serious attention, and note with appreciation the President's support for research and education in prior years. We hope that even within severe budgetary constraints there will be opportunities for special initiatives that respond to our common commitment to *LEARNING To Meet the Science and Technology Challenge.*

CHAPTER I.

BACKGROUND

The dramatic success of the United States of America in the 20th century has depended critically upon leadership in science and technology. While many other factors have also come into play, without great strength in both science and technology the nation could not have emerged in this century to achieve its current stature in world affairs. American industrial strength was built initially upon advances in technology and industrial production, and in the latter half of this century the discoveries of modern science have provided opportunities for new technologies to introduce entire new industries. On those occasions in the 20th century when warfare has been necessary, the contributions of science and technology to victory have been crucial. Extraordinary progress in human health in this century is also rooted in scientific and technological achievement. Even the food we eat and the water we drink have been influenced profoundly by science and technology in the past one hundred years. Although we have not yet found ways to ensure the equitable distribution of the benefits of science and technology, and we still need better control of some of the adverse consequences of technology, there can be little argument about the importance of science and technology to the emergence of the United States as a world leader in the 20th century.

The role of science and technology in the 21st century is very likely to be even more fundamental than in the century now coming to an end. It is not at all clear, however, that the United States will maintain world leadership in these fields. Indeed, in some sectors of technology that leadership has already shifted elsewhere. Thus we must face in this country a *science and technology challenge.*

In the first half of the 20th century it was primarily technology and industrial production that fueled the American ascension, and only after World War II did American science achieve pre-eminence. Whereas the progress of technology in America was largely the product of industrial corporations driven by market opportunities, the progress of science depended largely on the policies and budgets of the federal government. In other nations of the world, particularly in Western Europe and Japan, government policies have also shaped *technological* developments in recent decades, with results that have substantially altered the economic structure of the global society.

The success of these policies has prompted more deliberate consideration of the linkages among science, technology, and the economy in the United States, leading to the recognition that good science is necessary but not sufficient for advanced technology, which is in turn necessary but not sufficient for a healthy economy in the modern world. It follows that the science and technology challenge must be met if American prosperity is to continue to lead world standards. At the same time, other societal and institutional challenges must not be ignored. Unless we also preserve a sound basis for stable government and effective systems for world commerce, we will not achieve the full potential benefits of science and technology.

It is the central thesis of this report that the science and technology challenge must be met by learning, a term that we understand to embrace both teaching and research. Whether the necessary learning is accomplished in the classroom or the research laboratory, or merely through practical experience, it seems clear that learning is the key to progress in science and technology. The emphasis in this report is on precollege education, although implications are drawn when appropriate about both undergraduate and graduate university education and research. The President's Council of Advisors on Science and Technology has prepared a separate report on research-intensive universities and the federal government entitled *Renewing the Promise: Research-Intensive Universities and the Nation*.

In what follows, the learning agenda for the United States is addressed in four chapters:

Chapter II. Education In Science and Mathematics: Meeting the National Education Goals

This chapter addresses the need for building a stronger foundation for the understanding of science and mathematics throughout our society by means of improvement of elementary and secondary education in these fields for all of our children. At least three of the six National Education Goals adopted by the President and the nation's Governors relate to science and technology. Achieving these goals will enable us to meet the needs of most of our people. However, something more is required if the full potential of our population is to be realized.

Chapter III. Nurturing Special Aptitudes: Developing Superb Scientists and Engineers

This chapter focuses on special initiatives required to ensure that every talent for science and technology is fully developed so that society can derive full benefit from the contributions of superb scientists and engineers with the most advanced education. Experience tells us that aptitudes in these fields are often unrecognized or discouraged, particularly among girls and the children of disadvantaged groups. Specific strategies are recommended for nurturing these special aptitudes.

Chapter IV. Who Shall Lead the Way? Teachers of Science, Mathematics, Engineering, and Technology

This chapter deals with the teachers at every level who bear responsibility for instruction in science, mathematics, engineering, and technology. Teachers are the top priority of the federal Coordinating Council for Science, Engineering, and Technology, and for good reason. Unless our teachers are prepared to meet their responsibilities well, all else will fail.

Chapter V. Learning Through Research

In this chapter, a brief intimation is provided of the interdependency of teaching and research in the learning process. A full exposition of the research agenda for science and technology would require a separate report, but the inclusion of a small chapter in the present report is intended to convey a message: Teaching and research are complementary aspects of learning, and they should not be entirely separated.

The sixth and final chapter, *Recommendations*, is a summary of the major recommendations appearing throughout the report.

18

CHAPTER II.

EDUCATION IN SCIENCE AND MATHEMATICS: MEETING THE NATIONAL EDUCATION GOALS

PURPOSE: ACHIEVING NATIONAL GOALS

Of the six National Education Goals adopted by the President and the nation's Governors, three are particularly relevant to a report about learning in science and technology.

GOAL 3: By the year 2000, American students will leave grades four, eight and twelve having demonstrated competency in challenging subject matter including English, mathematics, science, history, and geography; and every school in America will ensure that all students learn to use their minds well, so they may be prepared for responsible citizenship, further learning, and productive employment in our modern economy.

GOAL 4: By the year 2000, U.S. students will be first in the world in science and mathematics achievement.

GOAL 5: By the year 2000, every adult American will be literate and will possess the knowledge and skills necessary to compete in a global economy and exercise the rights and responsibilities of citizenship.

The prosperity and even the full vitality of our democratic society are increasingly dependent on the creation and use of scientific information—on a body politic that values the scientific mode of inquiry, and on a relatively smaller number of highly-trained and qualified scientists and engineers who have the obligation to share their understanding of the fundamental laws of nature with the larger public and to apply those laws to the solution of human problems. The process of strengthening scientific literacy among all our citizenry and the process of training scientists and engineers are long-term and expensive. The federal role addressing both of these national interests is pivotal. However, responsibilities for identifying, preparing, and maximizing uses of our scientific talent must be shared by all levels of government and by other sectors of our society.

Clearly, this nation can no longer rely entirely on the conventional policies, standards, and practices that characterize most of our schools. The transformation of outmoded policies and practices can best be accomplished by empowering the individuals and groups who have already demonstrated their commitment to achieve the education goals, rather than by prescribing specific reforms at the national level. This report therefore provides the President and federal officials with a set of specific recommendations designed to encourage and reinforce the actions of state and local officials who are committed to achieving the National Education Goals.

Commitment to the Achievement of the Goals

The National Education Goals developed by the President and the nation's Governors in 1990 helped to reaffirm education's place at the top of the nation's policy agenda, and set the stage for establishing uniform and higher performance standards for all of the nation's educational systems, schools, and students. The high priority assigned to education by the President has stimulated a number of positive actions and the formation of new alliances by state and local officials, business leaders, and parent groups. Initial efforts have focused on reforms to improve basic education. The next stage of education reform should incorporate all levels and all those institutions engaged in informal and nontraditional education.

Achieving the national goals will require significant improvement in the teaching and learning of science and mathematics within formal school settings and in nontraditional environments. Our schools must ensure that all students learn the fundamental principles and content associated with the science disciplines. Our colleges and universities must assume a substantial role in the preparation of qualified teachers, in addition to the provision of other services and the conduct of basic research. And resources in a large and diverse group of special schools, museums, laboratories and centers must be marshalled in an expanded effort to engage and challenge our most talented students. Identifying and nurturing the best and brightest students in all of the nation's public and private schools is the responsibility of every educator and also of federal, state, and local officials, who have a special charge to guarantee equity as well as excellence.

Making Progress Toward Achieving the Goals[1]

The initial report released by the National Education Goals Panel indicated that we are making progress in some areas. Approximately 83 percent of our 19- and 20-year-olds are completing high school. For all students, this represents an increase from 81 percent overall. For African-Americans, high school completion rates have gone from 66 percent in 1975 to about 80 percent in 1990. Our schools are educating a much more diverse student body, and most of these students are mastering basic literacy skills. Reported incidence of drug use in schools is down, and achievement in science and mathematics has improved at most grade levels over the past decade, especially among minority groups. The National Education Goals Panel reports that these accomplishments are not trivial, and they result from purposeful actions. They reflect our commitment to educate all our students. The Panel did conclude, however, that accomplishments "fall far short of what is needed to secure a free and prosperous future."

Emphasis on Performance Outcomes

The National Education Goals have revolutionary implications for basic education. They are *performance* goals stated in terms of outcomes or levels of achievement. In the areas of science and mathematics, they require "demonstrated competency . . . in mathematics [and] science" sufficient to place U.S. students "first in the world in science and mathematics achievement" by the year 2000, when "every adult American will be literate and possess the knowledge and skills required in a

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[1] In July, 1990, the National Education Goals Panel was created and charged with measuring progress over the next ten year period. In September, 1991, the Goals Panel, consisting of six governors, four members of the Administration, and four members of Congress, released its first "report card." Legislation to extend the Goals Panel, with a reconstituted membership, is pending. On September 30, 1992, the Panel released its second "report card." The report relied on the International Assessment of Educational Progress (IAEP) data (unavailable last year), and school staffing and course taking data.

global economy." Moreover, the call for 90 percent of our young people to graduate from high school requires that the goals extend to virtually all school-aged children, including those for whom alternate educational strategies are required.

Previous efforts to improve education have often used input or process goals, which prescribed the experiences that students and teachers should undergo — for example, the amount and kinds of courses required of all students. Many of the new approaches adopted in the 1980s were process reforms, and although there is some evidence that these changes have contributed to modest progress in recent years, their results have been generally disappointing.

STRATEGIES FOR MEETING THE NATIONAL EDUCATION GOALS

The national debate on education reform is beginning to produce consensus for the following process:

(1) Continue to build support and consensus for achieving the National Education Goals.

(2) Set National Education Standards, defining learning standards to be achieved nationally, field by field. These standards should help to identify the common core of knowledge and competencies expected of all students.

(3) Develop a national system of assessments designed to measure performance and achievement of the National Education Standards. It is unlikely that a single national examination or a national curriculum will emerge from this process. However, a set of nationally approved "reference examinations" could be devised as standards against which alternative examinations would be "calibrated." In this way local preferences would be respected and a continuing development and improvement of tests would be encouraged.

(4) Develop a wide variety of responses to the challenge of educating American children to enable them to demonstrate through appropriate examination systems that they meet the National Education Standards. Ideally, every teacher in every school should be challenged to find new ways to meet this objective for every child. There is no need for a single, uniform "national curriculum" or federal regulations to exhibit the development of creative solutions on the part of local teachers and schools.

(5) Use small-sample statistical measurement instruments such as those developed by the National Assessment of Educational Progress (NAEP), to compare groups nationally and internationally. These surveys provide valuable and accurate information to the public about changes in the academic performance of our students over time and in comparison to counterparts in other nations.

Progress is being made in advancing each of the five steps noted above. The National Education Goals have been set by the President and the Governors. National Education Standards have been proposed by the President in the form of "New World Class Standards" and have been developed in certain fields (such as the Mathematics Standards adopted by the National Council of Teachers of Mathematics). Standards proposals are also being developed in the sciences by the National Research Council and the American Association for the Advancement of Science. Official standards will ultimately be adopted by the Standards Council under the direction of the National Education Goals Panel.

The development of the national system of examinations in Step #3 is also underway. The Pew Charitable Trusts and the John D. and Catherine T. MacArthur Foundation have financed the early stages of the New Standards Project, which is directed currently toward the development of reference examinations and calibration procedures in core subjects, including mathematics and science. It is essential for the national plan that this work go forward, and corresponding efforts are required in the basic sciences. The federal government has a responsibility to support the development of standards and a fair system of assessments.

Once Step #3 is accomplished in accordance with this plan, many of the existing regulatory and administrative barriers should be discarded in order to let teachers teach in ways that they believe are most productive and effective. The statistical measurement instruments developed in Step #5 should be able to confirm the validity of the national system of examinations in Step #3 as indicators that National Education Standards have been met.

The new presumption that virtually all students who work hard enough with qualified teachers will be able to meet world class standards differs from established practice in American basic education. There seems to be little doubt that adopting this new premise constitutes an improvement in educational policy that will serve virtually all Americans, including those who will ultimately become our scientists, mathematicians, engineers, and technologists. One might well wonder, however, if these new policies will be sufficient for this special population. (For more on this question, see Chapter III.)

Developing Performance Standards And Assessments[2]

If we expect all of our students to aspire to the same set of goals, and all to be held to equally high performance standards for the basic disciplines offered by schools, national standards and a fair system of assessments must be in place within the next two or three years. These standards should demand more than minimal levels of performance, and they should provide students families, educators, and policy makers with information for strengthening school programs and offering alternative services for students with special and different needs.

With support from the President and with the direct participation of the Director of the National Science Foundation and Deputy Secretary of Education, a set of recommendations for developing national education standards keyed to world-class levels of performance was presented to the Congress last January.[3] An early adoption of national education standards that reflect the highest possible expectations for all students, teachers, schools, and school systems is critical in progressing toward the achievement of the National Education Goals, particularly goals 3 and 4.

[2] This section refers primarily to the development of new content standards and skill requirements for students. It should be noted that the January 24, 1992, report by the National Council on Education Standards and Testing provides a rationale for national education standards, and suggests the need for (a) content standards, or "what schools should teach;" (b) student performance standards, or "what we would expect individual students to know and demonstrate;" (c) school delivery standards to ensure that the students to be tested are actually getting the opportunities to learn; and (d) systems delivery standards to determine the extent to which states and localities provide schools with adequate resources.

[3] On January 24, 1992, the National Council on Education Standards and Testing, chaired by Governors Carroll A. Campbell, Jr., and Roy Romer and comprising 32 individuals representing the Administration, the Congress, and education associations, presented advice on the desirability and feasibility of national standards and recommended long-term policies and mechanisms for developing voluntary education standards for states and localities.

Expectations for improvements in the performance of students can be emphasized only if achievement can be reliably measured. Today, we need greater confidence in assessment mechanisms and more understanding of how assessments relate to actual learning. Without such improvements, many in the education community feel it will be difficult to reorder the educational system on the basis of performance. In the absence of valid tests and standards that reflect the relative performance and progress of individual schools and students, we cannot expect to see the drastic changes and improvements that are necessary.

As assessment mechanisms are being improved, a complementary effort is needed in the area of curricular reform. Much good work is being done in this area, but implementation of the results in schools will not be easy. Project 2061 is one example that illustrates both these points, as are the proposals submitted for funding under the Eisenhower state curriculum frameworks competition. Moreover, testing standards must be coordinated with the major curriculum development projects underway.

The emphasis on performance implicit in the national standards and a new system of assessments constitute one of the most important educational reforms needed to meet those goals. This focus on performance rather than process must be accelerated and become pervasive throughout American elementary and secondary education.

ENCOURAGING INSTITUTIONAL REFORMS

A consensus has emerged that achieving the National Education Goals will require fundamental restructuring of basic education in America and the involvement of individuals and resources that typically are beyond the boundaries of traditional school settings.[4] Providing schools with access to resources available from advanced telecommunications networks is one important aspect in the redesign of schools in the decades ahead. Incremental improvements to school programs may be achieved by further incremental changes, but the magnitude of improvement needed to meet the goals calls for massive change in the educational system.

Effective reform requires a reduction in top-heavy administrative structures and increased reliance on school-based management that empowers principals and their teachers. However, governmental authorities will relinquish control to teams of teachers and principals at individual schools only if equity and accountability can be assured, which again raises the importance of educational assessments based on the same set of standards for all students.

Underlying the needed reforms of basic education is the recognition that the school is only one of many critical influences in a child's development. Only by shifting our focus from our institutions to our children can we truly address the challenges to our society. This strategy is particularly relevant for the retention of students at risk of dropping out, who may require strategies beginning with prenatal and child care even before formal school begins. If we are to strengthen our nation's work force and build better citizens, we must shape society's institutions to our children and not vice versa.

4 The AMERICA 2000 strategy encourages the design and development of a new generation of experimental schools, schools that incorporate wider community support and expert resources and services from other sectors.

Promoting Choice and Diversity

A fundamental change that will be required for the restructuring of basic education is the introduction of parental choice in the selection of schools appropriate for each child. Choice has many dimensions, ranging from permitting some children to choose "magnet" and "charter" schools within the public system to distributing government vouchers for children to pay for educational expenses at any school, public or private. Whatever system is adopted, it is important to provide some measure of academic quality to serve as a basis for choice. Widespread implementation of national standards and a system of assessments by school systems and individual schools will provide a firmer base for use by parents and students in the educational marketplace. Involving parents in education has great value, and giving parents some element of choice is often the beginning of a deeper parental involvement.

Focusing on the Quality of the Teaching Faculties

A promising strategy in the reform of basic education is rewarding exceptional teachers. Implementation often founders on the difficulty of assessing the quality of a teacher, but improved assessments of teacher performance, along with other means of evaluation, including peer review, provide important opportunities for improving the quality of the teaching force.

Such efforts are especially important in science and technology. Unless teachers at all levels of education understand and appreciate science and technology, significant improvement will be difficult. Improved teacher training programs to strengthen the content of science and mathematics and the quality of teaching are essential elements for achieving the National Education Goals.

Enhancing Mathematics and Science Learning for All Students

Progress toward the goal to make U.S. students first in the world in science and mathematics will require a shift in priorities at all levels of education and a concentration of limited resources to ensure that all students are challenged to their full potential. The objectives that must be addressed include: strengthening the early foundations for mathematics and science learning at the elementary and middle school years; improving the substantive and technical knowledge of teachers; and expanding the pool of undergraduate and graduate students in science and engineering, especially to include a greater proportion of women and minorities. Such objectives should guide our policy and resource allocation decisions for the next several years. No school, school district, or state should claim to be effective, or in compliance with the America 2000 strategy unless it has included more rigorous standards for its students and teachers.

Changes and improvements in our educational assessment mechanisms, new institutional structures, the expansion of alternative programs, more enriched curricular offerings, and more highly-trained classroom teachers are among the critical requisites to basic improvements in the way mathematics and science are taught and learned in our schools. Measurable improvements in the performance of our students in the areas of mathematics and science education will depend on the implementation of several of these systemic improvements. Far too many of our students compare unfavorably on standardized tests with their American counterparts in schools in the late 1970s and with their counterparts in other nations at this time. Today, unfortunately, most elementary school students receive only a rudimentary exposure to mathematics and science, and test scores reveal the dismal performance of too many of our students. On average, high school students take only one or two years of science. And, at the college level, a large number of liberal arts graduates receive their degrees without any significant study in mathematics or science.

Creating Environments for the Academically Talented

As a nation we are squandering our most precious resources — the young and promising students who are enrolled in our schools. In our efforts to provide an adequate education for all students, we have failed to provide vigorous and challenging opportunities for our most outstanding talent. Too many schools, teachers, and communities have been willing to accept minimum standards and a level of mediocrity that is a disservice not only to the brightest and most gifted students, but to all students and their families, if not the nation as a whole. All students deserve an educational program that challenges them to achieve the highest levels possible.

Increasing the number and percentage of young students who demonstrate the ability to reason, solve problems, apply knowledge, and communicate effectively will increase substantially the potential number of individuals who may choose to enter scientific and technical careers. A recent Technical Memorandum prepared by the Office of Technology Assessment points out: "Whether students respond to a professional calling or hear the call of the marketplace, they are lured to some careers and away from others — and schools are agents of this allure."

Nurturing scientific careers requires persistent effort. According to a report of the National Academy of Sciences, every educational and developmental stage is a potential point of intervention, and a comprehensive approach to nurturing science and engineering talent must address the whole pipeline. Special and informal educational programs, beginning at the elementary school levels, should be available to challenge and motivate students to consider and enter scientific careers.

Students with exceptional talents and interest in mathematics and sciences should be identified and encouraged to continue to register for advanced coursework and to locate programs and services that relate to their unique intellectual and vocational interests. Schools and the communities they serve should recognize their exceptionally talented students as valuable resources, rather than as social deviants or as individuals who can be accommodated only in special schools for gifted and talented.

THE ROLE OF THE FEDERAL GOVERNMENT

The federal government has had both direct and indirect effects on the education of scientists and engineers, but it is only one of the many actors in the system. The federal role in science and engineering education is most significant at the graduate level, more diffuse at the undergraduate level, and small in elementary and secondary education.

Educating Scientists and Engineers
Office of Technology Assessment, 1988

The federal government cannot mandate reform in the decentralized system of basic education in America. Nor should the federal government be expected to improve the performance of our schools, colleges, and universities in the absence of a public committed to educational excellence. Nonetheless, the role of the federal government at this time in our history may be pivotal and cannot be ignored.

Although the federal government is a junior partner in the support of education, its role in guiding the current wave of reform is critical. It has the capacity to facilitate, and where appropriate finance, the reform initiatives cited above. With limited discretionary resources for research, development, and demonstrations, the federal government can play a major role as a change agent. Financial incentives and "recognition awards" also provide appropriate leveraging to accelerate the reform process. In particular, we believe that the following federal actions warrant serious consideration:

- The federal government can provide incentives to states or regions pursuing any of the reforms described in the previous section, subject to constraints designed to ensure equity and equal opportunity. For example, federal funds might be used to facilitate choice for needy students, thereby providing an inducement to states or districts offering choice programs. Similarly, a national competition might be established to recognize and reward exemplary programs for restructuring education, just as the Malcolm Baldrige National Quality Award has recognized quality improvements in industry.

- The federal government can make a concerted, national effort to facilitate and coordinate state and local programs, both public and private, to deal with the school dropout problem. Successful drop out prevention programs could be recognized by the President and rewarded for their achievement.

- The federal government can encourage private corporations, universities, and national laboratories to work cooperatively with local schools, building on the many excellent initiatives already under way.

- In the areas of mathematics and science, the federal government can encourage effective programs to engage talented girls and minority students in science and mathematics, where they are now under represented.

26

- The federal government can invest in teacher education programs in science and mathematics and use forgivable loans and other inducements to attract to teaching young people with degrees in science, mathematics, and engineering.

- The federal government can support programs using modern communications technologies, including satellite, fiber optic, and wireless technologies, to expand access of both students and teachers to the most highly qualified teachers of science and mathematics.

THE PRESIDENT'S ROLE

Responsibility for our system of basic education in America rests fundamentally on the general population, who shape the learning environments of their children, elect their school boards and other influential politicians, and demonstrate their priorities by their behavior toward teachers and schools.

Our nation's leaders influence the attitudes and values of the electorate. The President, in particular, has a personal role that reaches beyond his authority as our nation's chief executive officer. In choosing his own priorities as a leader, he sets a standard for all to heed.

The President, in partnership with the Governors, has placed a great challenge squarely on the national agenda. Now all of the resources of leadership must be applied to meeting that challenge. federal budget priorities must be set, the activities of the federal agencies must be guided, and the President's personal commitment to education must continue to be demonstrated. With timely actions, and with a continuing and unremitting campaign of words and deeds, the President can secure his place in the history of American education.

CHAPTER III.

NUTURING SPECIAL APTITUDES: DEVELOPING SUPERB SCIENTISTS AND ENGINEERS

EXCELLENCE AND EQUITY IN SCIENCE AND ENGINEERING EDUCATION

Education in science, mathematics, engineering, and technology must reflect the twin goals of excellence and equity. While concerns for excellence and equity in education have a long history in America, their practical meaning and implementation depend on the socieral situation in which they are to be interpreted. At different times, the national agenda appears to have given a greater emphasis to one of these goals over the other, to the ultimate detriment of both. We must recommit ourselves to the integrated combination of these essential goals: excellence and equity.

In 1983, the National Commission on Excellence in Education reported as follows:

> The twin goals of equity and high quality schooling have profound and practical meaning for our economy and society, and we cannot permit one to yield to the other either in principle or in practice. To do so would deny young people their chance to learn and live according to their aspirations and abilities. It would also lead to a generalized accommodation to mediocrity in our society on the one hand or the creation of an undemocratic elitism on the other.

In the decade since the Commission powerfully reminded us that we are a "nation at risk," there has been real progress in improving performance at the lower levels of the distribution of academic performers in our society, but there has been an apparent decline among our best students. We must continue in the 1990s toward our objective of equity, but we must also aggressively advance the goal of excellence.

The National Education Goals and the America 2000 Strategy clearly encompass this perspective of both excellence and equity in education. Just as the utilitarian and altruistic aims of education have become intertwined, so have the twin goals of excellence and equity. High performance must set the pace in our society so that all can take pride in our national achievements and aspire to earn the rewards that accompany those achievements. In this chapter, a perspective is developed for a new fusion of excellence and equity in education.

STUDENT PERFORMANCE IN MATHEMATICS AND SCIENCE

Although real progress is reported in some areas, performance in mathematics and science among U.S. students in comparison to their counterparts abroad is still very disappointing. Recent national surveys indicate that nearly all our students have an understanding of basic mathematics and science information and have mastered basic facts and skills. Standardized tests also show that most of our students can demonstrate a basic understanding of mathematics and science. However, more than 25 percent of our 13-year-olds fail to demonstrate an adequate understanding of the content and procedures emphasized in elementary school mathematics, and relatively few students are able to apply knowledge, analyze data, or integrate information, as judged by international standards.

Students have difficulty in applying mathematics and science information to the solution of problems. "Science Report Cards" prepared over the last several years from the results of the National Assessment of Educational Progress document the general inadequacy of performance of U.S. students, despite the improvements noted in certain measures of performance. Over a period of two decades, the average mathematics and science performance of our elementary school students has shown overall improvement. But the average performance of our 17-year-olds on mathematics and science examinations has actually declined over this same period. Something is wrong, and the consequences to our society will be very serious.

There have been a number of international studies comparing American students with students from other countries. These studies consistently indicate the low relative performance of U.S. students in mathematics and science. Even the best students in the United States do less well when compared with the best students in other developed countries. On one recent study, both the top 1 percent and the top 10 percent of 9- and 13-year-old U.S. students scored near the bottom in mathematics and science, when compared with similar cohorts in twenty other countries. In a previous study, U.S. students in advanced placement courses in their final year of high school scored near the bottom in chemistry, biology, and physics when compared with 13 other countries. Another study found that in mathematics our best students performed only as well as the average students in Japan.

FACTORS RELATED TO PERFORMANCE

Curriculum and teaching are both associated with the poor performance data. Reports confirm the fact that teachers spend an inordinate amount of time on rote drill and practice and on the memorization of facts and insufficient time on problem-solving and reasoning exercises. There is evidence that existing testing programs and accountability requirements are expressed in a school curriculum that drives teaching in this direction. An emphasis on minimal requirements also contributes to the shortfall in reasoning and analytic skills by failing to motivate students to enroll in challenging and advanced courses of instruction, especially in mathematics and science. When science and mathematics are taught with an emphasis on memorization and rote drill, students become bored and "turned off." The declines in interest in science and the loss to society cannot be measured solely by comparative test scores.

If students are taught well, they usually also benefit by being taught more. The more such students are taught, the more they learn and the better they do on performance measures. Another contributing factor has to do with the maintenance of low standards and limited expectations. There is evidence that many experienced high school teachers have given up on pushing harder for student performance and that many parents do not support teachers who demand hard work. Several reports have indicated that secondary education, particularly the last two years, has become substantially less demanding than in previous years. Today's students may be receiving mixed messages about the values and benefits associated with the mastery of core disciplines and a solid education.

Yet existing multiple choice tests enable most school districts and states to report their students to be "above average." Low expectations and a teaching emphasis to assure the attainment of minimum competency levels have impaired our ability to provide a large number of our students with the mastery of higher-order skills associated with the study of mathematics and science.

Parental involvement in the education of students is another significant factor in explaining student achievement. In all nations surveyed, parental involvement and support for intellectual development have an important and positive impact on the success of children in mathematics and science learning in schools, regardless of the family's social or economic status. Mathematics and science achievement is also positively correlated with other family-support characteristics, such as the number of books in the home and time spent visiting museums and libraries.

TAPPING A RESERVE TALENT POOL: WOMEN AND MINORITIES

Changing demographics affect the talent pool for future scientists and engineers. First, there is an ongoing decline in the proportion of students of traditional college age in the total population. The U.S. Census Bureau reports that between 1980 and 2000, the 18-to 24-year-olds in the U.S. population will decline by 19 percent, while the overall population will increase by 18 percent. Thus, the size of the pool from which new entrants into the workforce are drawn is decreasing, with no evident decrease in the demand. Second, groups traditionally under-represented in science are growing disproportionately; by 2010, one in every three 18-year-olds will be Black or Hispanic, compared to one in five in 1985. Moreover, "persistence" in the study of mathematics and science with reference to gender and ethnicity is disappointing.

In the decade from 1981 to 1991, the total number of doctoral degrees in all fields earned by U. S. citizens experienced, first, a decline (dropping 8 percent by 1987 from a total of about 25,000 in 1981) and then a recovery to within 1 percent of its initial level. During this decade, however, there was a significant gender shift; women received 35 percent of the doctorates in 1981 and 44 percent in 1991. The fraction of doctorates earned by Asian-Americans grew steadily in this decade, from 1.9 percent in 1981 to 3.1 percent in 1991. Similar net growth was experienced by Hispanic-Americans (from 1.9 percent to 2.9 percent) and by Native Americans (from 0.3 percent to 0.5 percent), with less consistent growth patterns.

When comparing 1991 doctorates to 1981 doctorates in all fields by gender and the indicated race or ethnic divisions, all groups grew larger except white men and black men. When these data are broken down by academic discipline, a pattern of growth since 1985 emerges for engineering, physical sciences, and life sciences for all racial and ethnic groups, although some populations remain persistently small as is illustrated by the following Tables 1, 2, and 3.

Table 1
Engineering Doctorates: U.S. Citizens

Racial/Ethnic Group	1985	1987	1989	1991
American Indian	1	7	7	6
Asian	90	135	172	185
Black	19	12	23	43
Hispanic	16	24	33	48
White	1,094	1,327	1,574	1,659

Table 2
Physical Science Doctorates: U.S. Citizens

Racial/Ethnic Group	1985	1987	1989	1991
American Indian	4	10	18	14
Asian	100	104	117	143
Black	30	29	35	40
Hispanic	42	64	70	80
White	2,766	2,788	2,896	3,107

Table 3
Life Sciences Doctorates: U.S. Citizens

Racial/Ethnic Group	1985	1987	1989	1991
American Indian	18	16	12	19
Asian	128	145	138	186
Black	70	78	75	85
Hispanic	75	77	83	97
White	4,046	3,816	4,116	4,174

Source for Tables 1, 2, & 3: National Science Foundation, as reported by the Council of Graduate Schools, May 1992.

Women now receive more than one-third of all doctoral degrees in the United States. However, in the sciences, the number of women graduates is far less than representative. In 1990, women constituted less than 24 percent of the chemistry doctorates, less than 14 percent of the computer science doctorates, less than 11 percent of the physics and astronomy doctorates, and approximately 8 percent of the engineering doctorates.

In terms of career patterns, the changing role of women has resulted in positive developments for the science and engineering communities. Women now constitute more than one-half of the total undergraduate population and more women's career interests are moving away from the more traditional female occupations and toward business, medicine, and science. The percentage of females interested in engineering has steadily increased, but the overall number continuing in engineering remains noticeably small.

Thus, the appeal for greater participation of women and minorities in science is not merely altruistic, but provides a key toward addressing the concern for maintaining an adequate talent pool. Clearly, the reservoir of human talent from which scientists and engineers have been drawn traditionally will have to expand and include a larger proportion of women and minorities.

SPECIAL CHALLENGES FOR HIGH PERFORMANCE

Along with generally low standards and expectations for all students, there is evidence of failure to offer needed challenges for high performance. While nearly every state has mandated special services for "gifted and talented" students, implementation of successful programs is quite feeble. The nation spends only about two cents of every education dollar on special programs for "talented students." The most successful initiatives seem to involve specialized schools that serve only a few talented youngsters. A large proportion of this nation's outstanding talent remains substantially underdeveloped. Many of our schools make very little effort in identifying students with special aptitudes, talents, and interests in mathematics and science. Other schools devote a significant effort to identifying young students who are talented, but fail to provide them with advanced curricular offerings and experiences that would challenge their intellectual curiosities. The lack of interest and commitment on the part of many schools is particularly disturbing in the light of the aforementioned performance data that show America's best students performing less well than their counterparts in other nations.

The role of the family appears to be especially important in relation to high academic performance. Strong and early family support of talents is common for students who exhibit high performance. Parents of these students tend to stress academic achievement, hard work, and the full development of talents. It has been argued that the converse also holds. In families where there is a lack of interest in and support for intellectual development or where parents cannot provide the resources, interest, or encouragement, outstanding talent will too often remain substantially undeveloped. Experience tells us that poverty and deprivation have a particularly negative impact on achievement.

At all levels of government, policies and priorities guiding the development of our best and brightest students have waxed and waned, and the price of this nation's vacillating interest is reflected in recent international assessment surveys. The dilemma faced by school officials expected to provide an equal educational opportunity to all students while offering special and accelerated curricular experiences for a more limited number of exceptionally talented students is yet to be resolved. A key to the resolution of this conflict is the realization that a large fraction of the undeveloped talent resides in the very same student population that suffers from inequitable opportunities: females and minorities. Exceptionally talented white males are more likely to be supported in every way than equally talented females, racial minorities, or economically disadvantaged students. There should be programs specially designed to seek out and nurture talent among all students.

If there is an audible crisis in the education of the majority of our students, there is a quiet crisis in the education of our most gifted and promising students. Parents of the brightest children of all races and socioeconomic levels are increasingly anxious about the education their children receive. Most schools just do not provide the best possible education to our most promising students, particularly in science, mathematics, and pre-engineering education. Prior to the more advanced levels of education, a significantly large number of exceptionally talented students are getting side-tracked or turned off to scientific and technical education. Many of these students are female and many are students of color.

The way to identify talent is to provide enriching science and mathematics learning experiences to all children early in their educational careers. Classrooms must be filled with lively and challenging experiences that engage students. Then, from observing students in these settings, those that have special interests and talents will emerge. This is especially important for students who do not have access to enriching educational experiences in their homes. Through this process, not only students who are efficient learners and have a record of accomplishment can be found, but also those who "take" to high-level opportunities and want to delve deeper into the subjects presented. Special, high-level learning opportunities can then be offered to students with the interest and demonstrated ability. This melds the interest in providing rich opportunities to many students with the interest in developing exceptional talent.

Many researchers agree that exceptional talents can be developed among students who may not perform well on standardized tests. Traditional performance criteria and screening processes for determining who will participate in advanced learning opportunities in mathematics and science may not be sufficient, and new strategies may be required. Recent experience with student competitions employing a basic arithmetic operations game called *Twenty-Four Challenge* illustrates the phenomenon; in this case, the game seems to reveal special skills that may otherwise remain undiscovered.

POSITIVE DEVELOPMENTS

Despite the revelations that large numbers of students in the United States are performing at levels far below the expectations implicit in the National Education Goals, and below their counterparts in other nations, several positive developments can be cited. State policy reforms have increased the amount of time students spend in the core academic disciplines, and improved student learning of basic content knowledge is evident.

The Council of Chief State School Officers reports the following developments:

- From 1980 to 1987, 43 states increased mathematics course requirements for graduation and 40 states increased science requirements.

- The percentage of students taking Algebra 1 increased from 65 percent in 1982 to 81 percent in 1990; taking Algebra 2 went from 35 percent to 49 percent.

- Students taking Biology went from 75 percent in 1982 to 95 percent in 1990; taking Chemistry went from 31 percent to 45 percent; taking Physics went from 14 percent to 20 percent.

- The gap in achievement between European-American and African-American students has declined since 1982. Mathematics scores for the latter increased for all ages tested.

- There is a strong positive relationship between the amount of coursework and achievement scores.

Nearly all the states have raised high school graduation requirements, and student enrollment in mathematics and science courses is up. States and accrediting bodies are also strengthening requirements for teaching mathematics in schools.

UNDERGRADUATE EDUCATION IN MATHEMATICS, SCIENCE, AND ENGINEERING

A surprisingly high percentage of junior high school students express a preference for a career in science or engineering, a percentage that unfortunately declines precipitously as they move to upper level classes. However, interest in mathematics and science remains relatively high through the twelfth grade for the better students.

Among the very best high school students, interest in majoring in mathematics and science, and in the possible pursuit of scientific careers, remains particularly high. Of high school seniors who scored above the 90th percentile on the SAT quantitative examination in 1990, about 46 percent indicated an intention to major in science or engineering in college. Engineering was the field selected by the largest proportion of such top-scoring students, regardless of gender. Overall, American high schools have not done all that badly in developing a sufficiently large cadre of students of high quality who choose upon graduation to continue to meet the demands of rigorous science coursework.

Throughout undergraduate education, however, student interest in science and engineering continues to decline. A high proportion of well-qualified science, mathematics, and engineering undergraduate students "drop out" or change majors prior to graduation. The National Science Foundation reports an attrition rate of 60 percent for entering science, mathematics, and engineering majors. In one survey, 85 percent of the students who shifted out of the science, mathematics, and engineering majors said they were disappointed in entry-level courses; 65 percent of students remaining in their major said that their entry-level courses had seriously discouraged them.

Moreover, majors in these fields show little interest in graduate study. In 1990, more than 60 percent of the full-time college freshmen indicated aspirations for graduate study, but only 1.4 percent reported an interest in pursuing graduate careers in scientific research. Less than a third of baccalaureate science and engineering graduates enter full-time graduate study. Nearly one-half of the science and engineering doctoral candidates never earn PhDs. With little initial interest and poor persistence, graduate students in science and engineering show little prospect of meeting the needs of an increasingly demanding society.

Interest in a business major, which reached its peak of nearly 25 percent of college freshmen in 1987, is now in a period of steep decline, down to a little over 18 percent in 1990. Likewise, interest in science and engineering careers, and in some technical fields, has continued to drop steadily over the past few years. Student interest in engineering and computer science, which reached its highest level in 1983, has declined sharply. A 1991 American Council on Education and UCLA survey reports the following:

> While interest in majoring in biological and physical sciences has declined somewhat, interest in mathematics and statistics has experienced the largest relative decline, dropping from 4.5 percent in 1966 to a mere 0.7 percent in 1990. The recent 85 percent decline in the number of freshmen interested in math and statistics is quite alarming.

Overall interest in majoring in engineering is down one-quarter since 1982. Interest in computer science among college freshman has fallen by more than two-thirds in four years, and interest in science and engineering among women and minorities, after increasing in the 1970s, has plateaued and in some cases is dropping. Data for 1991 and 1992 are incomplete, but anecdotal reports suggest that recovery in undergraduate engineering enrollments may be beginning, after almost ten years of decline.

GRADUATE EDUCATION IN MATHEMATICS, SCIENCE, AND ENGINEERING

For each year over the past two decades, universities in the United States have graduated more than 30 thousand doctoral students. These students are drawn from the best undergraduate colleges throughout the nation and abroad. U.S. graduate programs are recognized as the best in the world. The numbers and quality of foreign students who flock to our graduate schools provide important measures of excellence. More than 20 percent of our doctoral graduates are foreign students, i.e., non-U.S. citizens who are here on temporary visas. In engineering, foreign students now represent more than half of the doctoral graduates at U.S. universities, and the percentages in mathematics and the physical sciences are becoming comparable to those in engineering. While these statistics testify to the quality of our graduate programs in the international community, they raise serious questions about U.S. students.

RESPONSES AND RECOMMENDATIONS TO MEET THE SCIENCE AND ENGINEERING CHALLENGE

In Chapter II, "Strategies For Meeting The National Education Goals" were presented. The responses and recommendations provided here are grouped in accord with those strategies.

(1) Building support and consensus for achieving the National Education Goals.

In building support and consensus for achieving the National Education Goals, it must be understood that the national goals encompass both excellence and equity in education and that these twin aspirations are intertwined. Among other things, this means that the consensus sought must be supportive of efforts to develop the talents of the young, respect effort, and reward merit.

To provide leadership in developing this consensus, it is recommended that a President's Science and Technology Award be established for high school students. This prestigious award might be presented at high school graduations. General criteria should be established, including the development of scientific knowledge or products that contribute to improvement of local communities (e.g., environment, health, manufacturing improvements). A "national yearbook" would be published listing winners and highlighting the names of a limited number of outstanding winners, with schools and teachers identified.

Schools, teachers, and students rarely have direct contacts with professional and practicing scientists and engineers. There are, however, many outstanding and dedicated scientists employed by public and private agencies who devote considerable time to schools and school-age children. To address this situation, it is recommended that a President's Science Education Service Award be designed to recognize highly-qualified scientists and engineers who have made, or are making, substantial contributions to precollege science, mathematics, or engineering education. States and national associations would make nominations. Annual awards would be sent to contributing scientists, and a limited number of biennial awards would be bestowed on a few individuals, highlighting contributions of minorities and female scientists in the process.

(2) Setting National Education Standards.

The emerging National Education Standards must project a perspective on talent, effort, and merit. This is especially important if National Standards are to avoid being minimal standards, a phenomenon that is correlated with the current deficiencies of our education system. One way of doing this is to make our high performing students the visible pace-setters for the standards in their schools.

Additionally, the National Council of Teachers of Mathematics (NCTM) has developed curriculum standards in five topical strands of mathematics. NCTM emphasizes that the standards are intended for *all* students. Students with special interests and abilities may pursue further work in one or more of the strands. This approach might be elaborated as a means of expressing the above perspective on talent and merit in education standards.

In considering this perspective, efforts to review standards and curricula in mathematics and science in other countries for their students preparing for college may be quite useful. A definition of "world class" standards in this country should involve "benchmarking" through comparison with the expectations of the other countries. This would provide a base from which to develop curriculum and pedagogy that combines the best of what we know about teaching and learning with the meaningful content developed through the standards. America's talented students should be as well prepared as talented students anywhere in the world.

(3) Developing a national system of assessment for students.

The New Standards Project (referred to in Chapter II) is endeavoring to couple the development of national standards in several subject areas with a national performance- based examination system. Several elements of that effort are quite relevant to issues involving students with special abilities. For example, the project subscribes to the view, suggested above, that a national examination system should reflect international standards of performance. Additionally, the idea is promoted that one's own effort to learn is important for achievement in mathematics and science, and not merely native talent or family background. This important work has been sponsored thus far principally by private foundations, but federal support will be required to realize the full potential of this initiative, which currently is limited to mathematics, reading, and writing assessments at three levels.

(4) Program responses.

Developing a wide variety of responses to the challenge of educating American children includes developing school programs and instructional models that are not only minimal or adequate for the broad middle group of students, but also appropriate for those with special abilities and interests. There are a number of ideas for such programs in the literature. Additionally, creating environments for the academically talented by identifying a diverse pool of the best and brightest students, and by nurturing scientific careers, must be among the efforts that arise among this wide variety of responses.

The overall effort to modernize and restructure elementary and secondary schools is a slow and excruciating process; yet reports by the governors indicate positive developments are well underway. Thousands of local communities are demonstrating responsible actions in preparing their students for performing at world class standards. A decade of national surveys and reports has contributed to the public demand for the creation of a new generation of schools. schools that require higher academic standards for all students. While the process of changing and improving schools is painstakingly slow, signs of progress are encouraging. These initiatives are properly at the state and local levels, to be encouraged but not mandated by the federal government.

When schools raise standards for all students, they should also be expected to increase the opportunities for all students to learn. A more diverse population of students suggests more diverse learning styles and interests. Local communities must be encouraged to exploit resources and expert talent beyond the formal setting of school campuses. The learning environment that characterizes *the next generation of schools* must extend into local communities and to a variety of resources. Telecommunications technologies will enable some students to undertake their own "electronic field-trips" or examine raw data in distant locations.

New educational partnerships involving local businesses, libraries, museums, colleges, and universities should be institutionalized, unless we expect to support intermittent crash federal programs in subsequent decades. Enhanced and accelerated learning opportunities for our most outstanding students should be integrated into the overall educational system. Programs must be individualized in order to challenge students who demonstrate the capacity and ability to benefit from enrichment. We should be quick to condemn any school system that permits students to be under-challenged. And we should be equally distressed with communities that fail to provide schools and teachers with the resources to challenge motivated and talented students.

There are three important federal programs addressing issues of special talents for elementary, secondary, and undergraduate students: the Young Scholars Program of the National Science Foundation, the Javits Gifted and Talented Education Program of the U.S. Department of Education, and the Research Experiences for Undergraduates program of the National Science Foundation. These programs should be reviewed and strengthened in the light of the recommendations made herein.

The central idea in nurturing talent in mathematics and science is to find ways to allow students to do "real" science as much as possible. The following are the kinds of activities that might be supported through use of federal resources:

- Federal facilities, notably DOE and NASA laboratories, should sponsor "summer laboratory schools." Six- to eight-week residential programs should be available to students from all over the country, perhaps following grades 7, 9, and 11. These programs should involve not only staff from the host laboratories but also a complement of college and university professors and teachers from junior and senior high schools. Much of the cost would be borne by reallocation of laboratory dollars, but stipends for students, professors, and teachers would be a needed addition so that all participants essentially have a summer job. Curricula would need to be planned by laboratory personnel, professors, and school teachers operating jointly, necessitating cooperative planning efforts during the academic year preceding the summer program and further work to evaluate and refine programs when the summer is over. There would also be a considerable task involved in planning the logistics of this program and hosting all participants on site. Most of these costs would be borne by the host laboratories, but it may be advisable to channel stipends to participants through other agencies, and perhaps to involve the Department of Education and NSF in the selection process. An interagency advisory committee including representatives from DOE, NASA, NSF, and ED may be needed to plan the program and define the guidelines for implementation.

- Support mentorships and placements with working scientists in settings other than federal laboratories. There are many examples that are very successful, especially with minority students and females. Placing high school students in scientific communities at an impressionable age can help them begin to see themselves as scientists and to understand the culture of science. The most successful programs have support for students and a facilitator who helps the students in ways that research scientists may not be able to help or support financially. These are not available to nearly enough students. Expansion of the NSF and ED programs is needed.

- Encourage collaborations through funding of institutions of higher education and elementary and secondary schools to provide opportunities for "hands on" experiences in science, including collaborations in disadvantaged areas.

- Provide funds to support summer institutes at magnet schools or Governor's schools. There is a great benefit for students with intense interests and talents to be placed together in a special learning situation and given opportunities to study intensively in their areas of interest. This recommendation supports the interest expressed earlier in school choice.

- Support efforts to develop high-level science materials for elementary and middle school grades. A recent study of science materials conducted by the U. S. Department of Education revealed that most of the materials currently used in schools do not involve higher level thinking or problem solving. These curricula should then be coupled with training funds for teachers in the federally supported programs.

For undergraduate students, activities analogous to those on the foregoing list may be designed to implement the basic principle of allowing students to do "real" science as much as possible. These include use of federal facilities, mentorships and placements with working scientists, collaborations between predominantly undergraduate institutions and research-intensive universities, summer institutes, and the development of high-level curriculum materials. Additional ideas are developed in Chapter IV when issues of undergraduate instruction are discussed.

Graduate study in most scientific fields, and increasingly in the high technology fields, is a virtual requirement for professional practice. As indicated previously, the statistics describing graduate degrees awarded in these fields are extremely discouraging, particularly with reference to U.S. citizens. Without reference to the problematic studies of supply and demand for specific advanced degrees, one might argue that the full development of society's human resources in these fields generates societal benefits, and thus structure incentives to such development. Perhaps the best strategies for the federal government in this domain revolve around graduate fellowships, traineeships, and loan forgiveness programs.

CHAPTER IV.

WHO SHALL LEAD THE WAY? TEACHERS OF SCIENCE, MATHEMATICS, ENGINEERING, AND TECHNOLOGY

INTRODUCTION

The commitments to new standards, curricula, and assessments are important foundations upon which to rebuild American education in mathematics and science in elementary and secondary schools. However, their implementation will require a higher quality teaching force in our schools. The preparation of elementary and secondary teachers and the maintenance of the strength of our undergraduate and graduate education also requires faculties in colleges and universities who are well prepared to carry out their instructional responsibilities. This chapter identifies problems and issues and provides recommendations aimed at this crucial matter of teaching excellence at all levels of education in science, mathematics, engineering, and technology.

ELEMENTARY AND SECONDARY TEACHING: CURRENT STATUS

There have been concerns expressed recently about the adequacy of the supply of elementary and secondary school teachers, especially in mathematics and science. Table 4 displays the most recent data available regarding teachers prepared in mathematics or science in relation to the total population of teachers.

Table 4
Elementary and Secondary Teachers: 1989-1990
(in thousands)

	Elementary	Secondary	Total
Public	1,389	968	2,357
Private	275	102	377
Total	1,664	1,070	2,734
Math Specialists	34	142	176
Science Specialists	22	128	150
Total, Math/Science Specialists	56	270	326

Source: National Center for Education Statistics

39

One needs to inquire whether these data represent an adequate number of appropriately qualified persons for teaching mathematics and science and what the prospects are for the future. A recent analysis by the Council of Chief State School Officers (CCSSO) considered various aspects of these issues (e.g. overall numbers of students and teachers, attrition rate of teachers, sources of new teacher hires, teacher qualifications). The overall conclusion of CCSSO was:

> In sum, the current data on science and mathematics teachers lead to three general findings: first, some indicators of teacher shortages have improved since the early 1980s; second, teacher shortages vary by specialty within science and mathematics and by state; and, third, the criterion of a "qualified teacher" needs to be specified to determine shortages of science and mathematics teachers. We also know that shortages are greater in certain school districts and schools.[5]

Another study found no teacher shortage (although the analysis apparently did not examine supply by field or specialization). This study also concluded that "this nation has probably never been in a better position to fill all its teaching positions with highly qualified adults eager to teach."

As suggested in the last comment, numbers of teachers alone do not fully illuminate issues of teaching and learning. Coping behavior of schools and school systems may confuse supply issues. For example, a RAND study argues that a defective system of rationing (i.e., offering fewer mathematics and science study opportunities to students) may hide the fact of shortages. Thus, there may be problems associated with expanding the numbers of mathematics and science teachers to provide more course offerings than are presently being offered. Given that increased study of mathematics and science is likely to be a requirement for improved student performance, the "rationing" factor may be significant. Higher achievement cannot be attained if not enough work in mathematics and science is available to students. Thus, we need to assure that the number of qualified teachers available and on the job is commensurate with the access students need to adequate instruction for high achievement and not reduce our instructional expectations to meet perceived low levels of teacher supply.

Many of the analyses regarding supply either do not address the issue of qualifications or are not robust enough on this dimension to permit firm conclusions. The widespread belief that persons more highly qualified to teach mathematics and science are less likely to be teaching or remain in teaching cannot be confirmed or denied by existing data.

There is also a widespread belief that traditional programs for the preparation of teachers are not adequately rigorous, especially in mathematics and science. In particular, there is evidence that educational methodology takes precedence over and may even displace "content." This is especially so for programs preparing teachers for the early grades. Such teachers are expected to teach all subjects, which confounds the issue of what should comprise appropriate academic preparation. The data in Table 4 show very few specialists in mathematics or science in the elementary grades.

[5] Reported by Blank, Rolf K., *State Indicators of Science and Mathematics Education 1990*, published by the Council of Chief State School Officers.

Reform of Teacher Education and Reform of the Conditions of Practice

Programs for the formation of teachers should be inspired by a vision of an *exemplary teacher*, which is a status achieved as a result of a significant developmental process, extending over a period of time, and encompassing preservice preparation and subsequent professional practice coupled with continuing professional development involving formal study. Such a vision is projected by the Standards of the National Council of Teachers of Mathematics. This perspective suggests concern with what teachers should know and be able to do, as well as the context and conditions within which they must practice their profession. Moreover, the attractiveness of teaching as a profession, including the conditions of practice, are significant attributes of teaching for recruitment and retention. Working conditions, such as the emphasis on paperwork and nonteaching activities at the expense of teaching time, salaries, and the rate of salary increases are all significant.

Redesign and improvement of university programs for the preparation and continuing professional development of teachers are essential. But it should be noted that all current proposals, including those of the Holmes Group and the Carnegie Task Force on Teaching as a Profession address twin goals: to reform teacher education and to reform the teaching profession. Inclusion of the latter goal indicates recognition that the quality of teaching in our schools depends on several factors in addition to the intrinsic quality of teacher preparation programs in our universities.

Teaching is not a mechanistic endeavor nor the fixed application of a set of rules. Effective teaching practice must go beyond reflex reactions to a teaching situation to reasoned judgments. Moreover, the *professional* practitioner is someone who has developed an awareness of the reasons for making these reasoned judgments. Professionals also enjoy a degree of *autonomy* and *discretion* regarding the organization and content of their work. Autonomy and discretion are the most attractive aspects of professional work. Schools, however, operate as if consultants, school district experts, textbook authors, trainers, and distant professionals possess more relevant expertise than the teachers in the schools.

Teachers often complain that the conditions they find in their schools do not allow them to use all the professional skills and knowledge they acquired through experience or teacher preparation programs. Further, bureaucratic management of schools proceeding from the view that teachers lack the talent and motivation to think for themselves goes against the idea of professional autonomy. In addition, the increase in testing as a means of monitoring student progress (and, in turn, teacher and school performance) leads to a narrowing of the curriculum in anticipation of tests. The tests constrain the professional discretion of teachers in ways that are not always appropriate and may even undermine good teaching. It is important that methods of measuring student performance be designed with the objective of improving genuine learning, so that effective teaching is properly motivated.

The goal orientation and accountability now being emphasized in schools, reinforced by testing and other performance measurement programs, are reasonable and proper. Moreover, if increased accountability for the results of teaching is accompanied by increased freedom in the teacher's choice of modes of instruction, then teaching can become a more satisfying profession that attracts and holds better qualified people. However, these same trends may stifle the idiosyncratic strengths of creative teachers if they manifest themselves as an undue reliance on mechanistic testing. In pursuing the performance-based education goals of previous chapters, one must be mindful of the implications for teachers and effective teaching.

REFORM OF HIGH SCHOOL TEACHER PREPARATION PROGRAMS: ACADEMIC CONTENT

Teacher education programs in the United States are eclectic and highly varied; their design responds more to administrative and logistical priorities than to a knowledge base. There is a need to define the *content knowledge* base and to express it in undergraduate and graduate curricula in mathematics and science. The major in a discipline is a good starting point for the development of this definition, especially for high school teachers. However, for several reasons, the nature and scope of the content base for teaching needs definition beyond the typical major.

The teacher's knowledge must go beyond concepts and facts of a domain to an understanding of the structures of a subject. For example, the biology teacher must understand that there are a variety of ways of organizing the discipline as is reflected by the red, green, and blue versions of the Biological Science Curriculum Study (BSCS) texts. These different versions are by no means intended to address different ability levels, but to present three distinctly different substantive principles for organizing the content.

Additionally, the science disciplines are interrelated. For example, there is a need to include basic mathematics for the effective study of science. In the case of a biology major, there is a need to include chemistry, physics, and earth and environmental sciences — as well as mathematics — in the program. Similarly, other science subjects are dependent on the study of neighboring disciplines by their majors.

Nowadays, science teachers are expected to address issues at the interface between natural science and social science. The prominence of controversial and so-called science-technology-society issues such as the ethical issues and societal problems associated with such phenomena as in vitro fertilization, genetic engineering, and nuclear waste disposal require successful teachers to have sophisticated knowledge of both natural science and social science. We must also be sensitive to the issue of applications; the inclusion of medicine in biology education, for example, or engineering in the physical sciences. These observations underscore the fact that the nature of what we expect children to know and be able to do is changing. Therefore, the measure of and preparation for competent teaching is also changing. The challenge for teacher preparation programs is not that we have incompetence, but that our standards are broadening.

A powerful trend in teacher certification and employment practices reinforces the call for a closer look at the content base for science teaching. Many science teachers are required to teach more than one science subject. School managers (i.e., principals and superintendents and their designees, who exert considerable influence in the selection of teachers) want as much flexibility as the managers of any organization. They want less regulation rather than more.

As a result, one sees a major trend toward *broad field* certification for high school teachers in contrast to the traditional certification in specific fields of biology, chemistry, physics, etc. Two-thirds of the states certify science teachers through broad field as well as in specific fields. In Georgia, for example, certifying biology, physics, chemistry, or earth science *specialist* teachers is possible, but the certification of the *broad field* science teacher for all four subject areas is not only possible but the route preferred for teachers by school officials for reasons cited earlier. The broad field certification is the more prevalent route for science teachers and typically involves a major in one science field

42

and significant academic work in the other fields. However, despite the fact that the total quantity of science study for broad field certification is substantial, there is no degree program in the university preparing the broad field teacher. Certification is achieved through a special review of the candidate's course record by the state department of education. This course record frequently has much less coordination and integrity than is desirable and possible.

For all of these reasons, there is a need for a "Science for All Science Teachers," an analog to *Science for All Americans*. Science for All Americans is a comprehensive effort, sponsored by the American Association for the Advancement of Science, to have groups of mathematicians, scientists, and engineers define "the knowledge, skills, and habits of mind that all students should have acquired by the time they finish high school." This work is being used as the basis for the subsequent effort by the National Research Council to design standards for curricula in school science.

In the very same spirit, a major effort should be undertaken to have teams of mathematicians, scientists, engineers, and educators develop a Science for All Science Teachers. This development will then form the base for the design and development of programs for the preparation and continuing professional development of science teachers. The NCTM standards include standards for teaching as well as for curriculum and assessment in mathematics and were the basis for a subsequent effort by the Mathematical Association of America to develop and promulgate standards for teacher education in mathematics. This sort of work needs to be carried out for science. Moreover, both mathematics and science need models of exemplary programs based on these developments.

INSTRUCTIONAL MODELS

There is substantial evidence that exposure to good teaching is an important factor for the preparation of teachers. Indeed, the evidence indicates that the old adage that we teach as we have been taught is quite true. This is all the more reason why we must focus on the models of content teaching to which prospective teachers are exposed in the university. This issue is more fully developed in the discussion of undergraduate teaching below.

PEDAGOGY

There is a widespread belief that teacher preparation programs give too much emphasis to pedagogy over content. This relative emphasis is all the more a problem because it is also believed that pedagogy, as such, is much less robust as the object of academic study than is the study of content. This issue should be confronted head on. There is no question that teachers need understanding of the nature of the learner and of effective instructional design and practice. The substantial literature on the subject and practical experience should guide this debate. Content-specific and context-specific pedagogies are especially promising aspects of this issue that should be pursued. The foregoing recommendations regarding science and mathematics content for teachers should encompass this issue.

TECHNOLOGY

The application and utilization of technology in education is relevant to both of the twin goals. Certainly, teacher education programs must incorporate the latest and best preparation for technology applications. There is a large literature on this topic to inform program design. However, schools must also provide teachers as professionals with the appropriate support to facilitate effective applications. This last is a serious problem. Traditionally schools do not equip teachers with telephones, let alone more sophisticated communications and instructional technologies. Thus, advancing the use of technology is of special significance for the goal of strengthening the profession of teaching.

ELEMENTARY MATHEMATICS AND SCIENCE

Many of the foregoing remarks regarding academic preparation and instructional models for high school teacher preparation and development apply to elementary school teaching as well. However, there is a special problem at the elementary level that requires special responses. It is still the case in the vast majority of elementary schools in America that a teacher teaches all subjects to the same group of children. While there is evidence that teachers are assisted by specialists in areas such as art, music, or physical education, there are few specialists of mathematics or science in the elementary school. Because the elementary teacher must teach across so many areas, preparation programs do not include in-depth study in any subject, let alone mathematics or science. Even in states that have moved to requiring an arts and sciences degree before entry into a professional development program for elementary teachers, few candidates are electing to major in mathematics or science.

While our call for reexamination of the content knowledge base for high school teachers applies to elementary teachers as well, additional steps are needed to deal with this special problem. School restructuring that develops models for the instruction of young children built on the concept of specialists in mathematics and science must be pursued along with other ways of organizing the school curriculum and utilization of teachers and other instructional resources.

The National Elementary Science Leadership Initiative, a four-year project of the National Science Resources Center supported by the National Science Foundation, offers an especially attractive model that actively engages mathematicians, scientists, and engineers in elementary science education. The program is based on the idea of each school district forming a coalition of outstanding elementary teachers (as a district leadership team) with a small team of local scientists and engineers. The major role of the coalition is to create a science lobby to help promote change. The coalitions in various school districts would, in turn, be networked for the exchange of ideas and mutual assistance. The program is designed to provide two-day mini-courses in connection with the national meetings of major American scientific societies to facilitate the development and preparation of the local coalitions.

LINKING TEACHER EDUCATION REFORM TO SCHOOL REFORM

In conjunction with the National Education Goals and the America 2000 Strategy, many schools are introducing changes and innovations. Restructuring is the byword, and there is a growing number of sites where this is occurring. The Holmes Group, the Goodlad Network, the Coalition of Essential Schools, and other efforts aimed at the reform of teacher education are suggesting co-reform — the linking of university programs for teacher education to restructured and exemplary schools and giving these schools a larger role in teacher education. This, of course, is directly relevant to the call for strengthening teaching as a profession.

Through such co-reform efforts, new models for the induction of beginning teachers into the profession through formal paid internships or mentoring programs involving master teachers can be developed. Moreover, in the spirit of the foregoing, the teachers can be encouraged and supported to become active catalysts of change in mathematics and science education.

Such co-reform partnerships between universities and schools can also provide a basis for investigation of context-and site-specific teacher education. For example, promising programs are being proposed and developed in science for Native Americans. Obviously, the scientific content must be the same for all students, but the mode of presentation can be effectively adapted to the cultural characteristics of the students. This idea can clearly be generalized either in terms of the context created by the local audience for science education or of special characteristics and resources of the community (e.g., geography, geology, technical industry).

TEACHING STANDARDS

The work of the National Board for Professional Teaching Standards (NBPTS) is an endeavor of enormous national significance and appears to be particularly promising. NBPTS aims to develop a system of National Board Certification designed for experienced, not beginning, "teachers whose preparation and experience have enabled them to understand how theory translates into practice, to ascertain what works, to learn how to judge student behavior and performance, and to practice as mature, professional decision-makers." To this end, NBPTS is pursuing an agenda of policy and reform issues related to National Board Certification that includes the following priority areas: (a) creating a more effective environment for teaching and learning in schools; (b) increasing the supply of high-quality entrants in the profession, with special emphasis on minorities; and (c) improving teacher education and continuing professional development. In pursuing its agenda, NBPTS is working closely with other groups and organizations — for example, the National Council of Teachers of Mathematics (NCTM) and the NCTM standards.

UNDERGRADUATE EDUCATION

Poor instruction is a broad based policy issue at every level. At the undergraduate level, this issue is associated both with the specialized programs for the preparation and retention of prospective scientists and engineers and with the quality of undergraduate education in mathematics, science, and engineering offered to students majoring in non-science fields.

Students in the sciences have the highest defection rate among all undergraduate students. A Sloan Foundation Report (1991) on factors contributing to the high attrition rates among science, mathematics, and engineering majors concluded "that some, possibly large, proportion of (this) attrition reflects a wastage of students with good potential," and "that important contributors to such wastage are institutional factors which, if addressed as a matter of priority, would significantly improve retention." Of the negative factors cited by undergraduate science, mathematics, and engineering majors, "poor teaching" and academic support was cited by over 50 percent inadequate high school preparation was cited by only 4.7 percent. This is the perspective of the students, and it cannot be ignored.

Among science majors, the "pre-occupation of faculty with their research to the detriment of their teaching" is among the most commonly cited commentaries about the condition of undergraduate science education. The relative popularity of science-related courses during the earlier school years seems to deteriorate quickly among first and second year college students. The high attrition rate among science and mathematics majors during the last two years of undergraduate education is attributed more to the students' perceived opportunities in research, teaching, and professional practice.

Regarding mathematics, science, and engineering education for majors in non-science fields, there seems to be a consensus among many observers of the undergraduate experience that the lower division, or entry-level, course requirements suffer from serious neglect. Introductory courses rarely take into account the intellectual diversity of enrolled students, and rarely do these students have direct access to practicing researchers or laboratory experiments.

Considering the increasing pace of scientific and technological developments, most colleges and universities have yet to provide undergraduates with the foundation they will need to function effectively in their careers, whatever they may be. Most colleges and universities require only two or three semesters of science-related courses for non-majors, and these courses are generally described as "watered down."

Strengthening the quality of instruction could be a major factor for improving retention. One mathematics professor and member of the Mathematical Science Education Board (MSEB) stated that it is clear to virtually everyone that the present system of science education works well only for those *already* committed to science. Concern about the inadequacies of undergraduate instruction is growing nationally. The Mathematical Sciences Education Board (MSEB) is in the forefront of providing leadership to redress this problem. Its recent report, *Moving Beyond Myths*, calls for the development of models of good instruction as the first priority in the reform of undergraduate mathematics. Similar appeals are being made in the science disciplines. As indicated earlier, improved models of undergraduate content instruction would greatly improve elementary and secondary teacher preparation in content as well as pedagogy.

Science and engineering fields are also developing plans to provide instruction that will be more effective in attracting and retaining well-qualified students. A recently published report provides an especially cogent analysis of the teaching situation in colleges and universities in mathematics, science, and engineering. It is titled *America's Academic Future: A Report of the Presidential Young Investigator Colloquium on U.S. Engineering, Mathematics, and Science Education for the Year 2010 and Beyond*. The report presents Five Principal Points to assure high quality instruction in engineering, mathematics, and the sciences:

- Encourage and reward teaching excellence, instructional scholarship, and public service as well as research.

- Increase substantially resources for instructional innovation and curriculum renewal, especially for undergraduate education.

- Assume primary responsibility for public understanding of science and technology, principally through high-quality precollege teacher preparation and lower division undergraduate instruction.

- Assure adequate career participation in engineering, mathematics, and the sciences by all segments of society, particularly careers as precollege and college faculty.

- Encourage the development of discovery-oriented learning environments and technology-based instruction at all educational levels.

These recommendations come from a colloquium of Presidential Young Investigators (PYI) selected for their awards in the years 1984-89. Their promise as researchers provided the basis for their selection. Thus, this group has an unusual degree of credibility for addressing issues of instruction.

These principles of the PYI colloquium recommendations encompass a number of issues, but three are highlighted here as of special concern and interest. First is the significance of instructional quality in content areas of college and university teacher preparation programs for elementary and secondary school teachers. Improved content programs and instructional models are essential if teacher preparation programs are to be reformed.

Second is the idea of making education in mathematics, science, and engineering more accessible to more people. Often, university faculty members tend to have an interest in only those undergraduates they teach who are interested in and motivated to doctoral study in the discipline. The call is to provide stimulating undergraduate majors in, say, physics even for those students who do not wish to pursue graduate study.

This issue of accessibility has many other ramifications as the PYI principles are studied and implemented. What is needed is to make the study of mathematics, science, or engineering more like a "liberal art " The serious study of literature or of history is undertaken by many who do not plan to become specialists in these areas but regard them as suitable preparation for careers such as teaching, journalism, or law. A solid grounding in mathematics, science, or engineering must become similarly regarded as appropriate and effective preparation for a variety of career options.

The third issue is perhaps the most challenging of all: effectively addressing the interrelationships among mathematics, science disciplines, and engineering fields. The terms interdisciplinary, multi-disciplinary, and cross-disciplinary come to mind here. These terms are used sometimes synonymously and sometimes distinguished by nuance. The basic problem is that teaching is too specialized and would benefit from a movement toward synthesis and less specialization. In any case, reform of undergraduate education may well turn on the success with which this issue is addressed.

On the basis of these considerations, a major overriding recommendation is offered. There is a significant investment on the part of the federal government, mostly through the National Science Foundation, supporting efforts for the improvement of undergraduate education in mathematics, science, engineering, and technology. We recommend that the relevant programs be designed to promote the aims developed herein.

GRADUATE EDUCATION

Graduate education presents a special problem because of the close relationship to research in mathematics, the sciences, and engineering fields. Accordingly, this area will be more fully developed in the new study of the health of research-intensive universities currently being undertaken by PCAST. However, two items are highlighted here as precursors to the report of this new study.

First, there is a high proportion of foreign students in mathematics, science, and engineering graduate programs in the United States. It is sometimes argued that these students do not displace Americans. However, others argue the opposite point. In any case, the dynamic of selection is quite complicated. While this may raise questions about whether the capacity of graduate education exceeds that which is required to meet national needs, graduate study (by both foreign and American students) is an integral part of research programs. From this point of view, it might be argued that the United States gains by having high-quality input. Given the principal points of the PYI study discussed above and the comments made about expanded access to programs, we believe that stimulus of American interest in graduate study in mathematics, science, and engineering is in order. Accordingly, we recommend that increased incentives be provided (e.g., through fellowships and traineeships) for the recruitment and retention of U. S. graduate students in graduate programs in mathematics, science, and technology.

The second issue is closely related to the first. Graduate education in the most distinguished science and engineering departments in American universities is too often conducted in an atmosphere in which undue value is attached to the replication of the faculties' careers. Less famous academic departments tend to emulate the research culture of the most prestigious institutions, providing too little attention to the needs of industry or even to the educational requirements of their students. Unless significant changes in the culture of graduate education can be achieved, the potential for financial support and domestic enrollment will probably not be realized.

CHAPTER V.

LEARNING THROUGH RESEARCH

It has become customary to discuss the learning experiences fostered in an academic environment in bifurcated terms, separating teaching from research as though they were unrelated activities. This is at least in part because teaching is frequently understood to be a process of transmitting information from authority (the teacher) to the learner. The student is in this model the "clean slate" on which new information is to be inscribed, or the "empty vessel" into which fresh knowledge is to be poured. But there is evidence that the clean slate and empty vessel metaphors are not accurate. In fact we learn at all levels through some combination of communication from authority and personal exploration (research). Because both of these learning activities have become highly organized and expensive operations in American colleges and universities, with different financing strategies and different emphases within different kinds of institutions, we often separate teaching and research in our analyses of higher education. This may be convenient for administrative purposes, but such artificial separation of intellectually linked activities can be misleading, with dangerous consequences.

The title of this report is *LEARNING to Meet the Science and Technology Challenge*, and logically one should expect learning through research to be included in its scope. However, there is a separate study of research-intensive universities and the federal government in preparation by the President's Council of Advisors on Science and Technology, and it would be both redundant and confusing to incorporate a digest of this material in the present report.

Thus, a dilemma is posed: How can we omit "learning through research" from this report without fostering the illusion that effective teaching can be advanced without corresponding support for research? The resolution attempted here is the present chapter, designed to recognize the fundamental linkage between teaching and research without incorporating any substantive treatment of the latter activity.

A distinction should be made, however, between "learning through research" and "research about learning." The fields of science, mathematics, engineering and technology require by their nature a significant amount of learning through research; much learning in these fields is individual and experiential in character. But scholars in these fields have given very little attention to the important business of doing research on the learning process. Specialists in the fields of education and psychology do care about research on learning, but until recent years few among them have been focusing their interests on the learning processes that are peculiar to science, mathematics, engineering, and technology, noting the variations among these disparate fields.

We are persuaded in PCAST that the National Education Goals would be more readily achieved if we had a better understanding of the learning process. We are particularly concerned about the need to discover new ways to engage young minds in modes of thought peculiar to science, mathematics, and engineering. We are concerned that whole sectors of our population, particularly females and certain minority groups, are not pursuing careers in these fields in numbers proportional to their talents, and we want to encourage the systematic investigation of this phenomenon.

We note, for example, the difficulties encountered in attempts to measure mathematical skills without inadvertent reliance on verbal skills for mathematical performance. The unexpected success of girls and minority children in such pure "math games" as the *Twenty-Four Challenge* program mentioned in Chapter III raises questions about the possibility of significance beyond the evidence of adroitness in arithmetic. Is there something fundamental revealed by the experience in such competitions in basic mathematics, which often yield winners who surprise their teachers? Are we missing an opportunity to identify and nurture talent? Do children learn mathematics and science better with games today than in past generations, and learn less well through familiar learning drills? Do children with different cultural backgrounds respond differently to educational challenges in science, mathematics, engineering, and technology? Would an early introduction to technology better motivate learning about science and mathematics? These are all important questions, and we do not know the answers. The federal government should sponsor serious research programs designed to provide these answers. We need more research on learning.

Contemporary thinking and research are providing important insights that indicate that students construct their own understanding and do not mirror simply what they are told or what they read. Moreover, the learner's formulation of understanding is based on a great deal of prior information. A child's cultural and familial environment affects how information transmitted in a classroom is processed in the child's mind. These "environmental" factors affect what is retained by the child, what is pursued further, and what is virtually ignored. Thus, students come to their science classes with surprisingly extensive theories about how the natural world works. These naive theories affect what they perceive to be happening in the classroom and in laboratory experiments. These naive theories are developed as a natural human tendency to come to grips with and find order in a world that, especially to a child, seems incredibly complex. Moreover, they often continue to attach their incorrect and naive understandings to situations even after instruction supposedly provided correct versions. For example, one piece of research showed that college students could successfully complete an introductory physics course, presumably having learned Newton's Laws of Motion, and yet persist in believing the contradictory Aristotelian "impetus" theory of motion, which holds that the capacity to initiate motion is inherent in an object, which in the absence of such initiative tends toward a normal state of rest.

From this perspective, engaging students as active participants in learning underscores the importance of our theme, *Learning Through Research*. There are several ways that contemporary approaches to teaching and learning give expression to this theme:

Technology Linking Research to Education. It was noted in Chapter III that the central idea of nurturing talent in mathematics and science is to find ways to allow students to do "real" science as much as possible. This prescription has significance quite broadly for education in mathematics and science. Contemporary computing and telecommunications tools make it possible for researchers to share their current research activities with high school teachers and students. For example, researchers in computational physics develop and use software models of microscopic molecular dynamics. Students in a variety of different junior and senior high schools are now using those same software models to develop their understanding. Similarly, visualization technology and software for mathematical symbolic manipulation have the potential for significantly changing the scope and sequence of school and college mathematics and science courses. In these ways, novices can acquire a qualitative understanding of complex models and simulations that previously required sophisticated quantitative reasoning.

Direct Access to Scholarly Materials. The idea of the teacher as the sole epistemological authority for the student has long been obsolete, but the norm in practice is still the combination of one teacher and one textbook as epistemological authorities. Most students view scholarly materials only through the filter of a textbook, an important technology witn many shortcomings. Textbooks tend to establish the school as the ultimate authority with regard to knowledge, thereby diminishing appreciation of the importance of exploring original sources of knowledge. Libraries have offered some counterbalance to this role; however, communications and computing technologies can far surpass libraries in opening the world of knowledge to teachers and students. Through these tools, teachers are able to select primary rather than secondary resources for the curriculum. This will help both students and teachers to become informed and independent decision makers.

Research Participation. Two current projects illustrate how research participation experiences can be made available to large numbers of dispersed students. Project JASON provides live television images of ongoing deep sea exploration, with some opportunity for remote interaction between students and scientists. More than thirty universities and science museums serve as downlink and coordinating sites. Each recruits students and teachers in its respective area, coordinates viewing of the live transmission of undersea exploration, presents workshops for teachers, and generally implements the blending of undersea exploration with school programs for science education. A second project is KIDSNET, an NSF-funded activity to facilitate school teacher and student access to INTERNET. National Geographic, one of the sponsors, structures research activities for students who then share data.

CHAPTER VI.

RECOMMENDATIONS

Conclusions and recommendations have been woven into the text of this report, integrated with arguments for their adoption and descriptions of context. The purpose of this final chapter is to distill the recommendations from the preceding text and to record them for convenient access.

The President's Council of Advisors on Science and Technology was established to advise the President, and by extension the executive branch of the federal government. The nature of our democracy requires that such advice by directed to the United States Congress as well. One might expect therefore to find a PCAST report limited in its recommendations to those directed primarily at the federal government.

Responsibility for advancing learning about science and technology is, however, a shared enterprise in the United States, requiring the coordinated efforts of all sectors of society, and it would be inappropriate to limit the recommendations in this report to those directed to the federal government. What follows therefore reaches somewhat beyond that narrow interpretation of the PCAST charge, although greater specificity is attached to the recommendations to the federal government. Thus, the format of this chapter distinguishes "general recommendations" from "recommendations to the federal government," and further defines a set of "recommendations to the President."

GENERAL RECOMMENDATIONS

1. Recognize that the key to success in meeting the science and technology challenge is *learning*, which is advanced by research, teaching, and a wide range of human experiences throughout life. The challenge to the United States is not a simple matter, and there will be no quick, easy, or painless solutions. PCAST recommends a moratorium on the search for a "cure" to America's sick schools that is analogous to a magic pill with no side-effects; we must plan and execute diverse strategies for the longer term, and persist in their implementation.

2. Accept the *process* that will lead to improvement of basic (elementary and secondary) education in America. This process has been defined adequately:

- Establish National Education Goals.
- Establish National Education Standards.
- Establish a national system of performance assessment instruments and procedures (but not a federally mandated test).
- Develop local and regional strategies for meeting the National Education Standards using approved methods of assessment (but not a federally mandated national curriculum).

■ Develop statistically valid survey instruments (such as those of the National Assessment of Educational Progress (NAEP), to define a single federally sanctioned statistical measurement of the comparative progress of groups of students and teachers (but not of individuals). Also, press ahead with the serious challenge of implementing the results of this process.

3. Abandon the illusion that basic education is terminally ill and higher education is robustly healthy in America. There are genuine strengths and severe weaknesses at all levels, and there is a great need for integrated, systemic improvement that is perhaps best described as belated adaptation to a changing world. Problems are perhaps most severe in the fields of mathematics, science, and those disciplines (such as engineering) that build upon these foundations, and these domains of study may be most critical for our national recovery.

4. Recognize that education cannot be significantly improved without serious attention to the development of *teachers* at all levels, particularly in the fields of mathematics, science, and those disciplines (such as engineering) that build upon their foundations.

5. Accept responsibility in all sectors of American society for improving education, forging partnerships including families, churches and community groups, business, labor, and government at all levels to join with the schools, colleges, and universities in a concerted effort to rebuild the American dream on the foundation of learning.

Recommendations to the Federal Government

1. Advance the reform agenda of the America 2000 program. In this context PCAST urges the following:

■ Shift focus from programs and institutions to individual children, recognized as both national assets and potential liabilities. Emphasize efforts to stimulate learning by all children to keep them in school and maximize their development.

■ Preserve and exploit more effectively the variety of options now available to Americans.

■ Diversify strategies, encourage more options, and offer more choices to children and their parents.

■ Provide special incentives for females and under-represented minorities in the study of science, mathematics, engineering, and technology at all levels.

■ Reward exceptional teachers, and provide effective training in science and mathematics for both teachers in service and student teachers.

■ Provide access to telecommunications networks linking schools, colleges, and universities, so that resources can be shared most effectively.

■ Support the continuing development of National Education Standards in mathematics and science.

■ Support curriculum development and laboratory learning in mathematics and science.

- Support the development of reference examinations and other means of performance evaluation.

- Encourage and support community partnerships committed to systemic reform of basic education with the goal of institutionalizing permanent collaborations among all sectors of society.

2. Intensify commitment to excellence as well as equity in basic education through federal support of such programs as the following:

- National Science Foundation "Young Scholars Program;"

- Department of Education "Javits Gifted and Talented Education Program;"

- Summer Laboratory Schools at NASA and DOE laboratories for promising students following grades 7, 9, and 11 in residential programs involving schoolteachers, professors, and laboratory personnel;

- Summer Institutes at "magnet schools," "Governor's schools," and other special academies for students showing promise in math and science; and

- National Science Foundation "National Elementary Science Leadership Initiative."

3. Stimulate education reform at the college level in mathematics, science, and engineering by supporting such initiatives as the following:

- Encourage with appropriate incentives the integration of federally sponsored university research with the education of both graduate and undergraduate students;

- Provide contracts and grants for curriculum development and instructional innovation, subject to peer review for grant award and report publication, to replicate incentive structures now established for research;

- Encourage and reward teaching excellence, instructional scholarship, and public service as well as research;

- Support the use of technology to improve productivity in instruction;

- Encourage undergraduate majors in mathematics and science to become elementary and secondary school teachers, using such incentives as fellowships, traineeships, and loan forgiveness. Also, encourage university faculty to attach new value to undergraduate majors not destined for Ph.D.'s.;

- Encourage the development of high-quality programs for technology education linked to the workplace;

54

- Encourage programs that enhance the prospects of success for students who experience delayed access and entry to education in mathematics, science, engineering, and technology;

- Support programs to strengthen mathematics and science backgrounds for current teachers as well as student teachers, with particular attention to the need to develop more elementary school specialists in mathematics and science; and

- Increase support for graduate education in engineering, science, and mathematics with fellowships, traineeships, and loan forgiveness programs, including teaching responsibilities as an integral part of these awards.

Recommendations to the President

1. Maintain the leadership initiative in education, using every opportunity to reinforce the public's understanding of the priority that must be given to education at all levels, including such devices as the following:

- Keep education at all levels in the foreground of political debate;

- Keep education at all levels central to such seminal speeches as the annual State of the Union address;

- Establish for high school students the President's Science and Technology Award;

- Establish for volunteers in the schools the President's Science Education Service Award; and

- Recognize recipients of established teaching awards at both university and basic education levels; a letter of commendation from the President represents an important statement of values.

2. Establish budget priorities to match actions to words, supporting the initiatives suggested in this report as well as the ongoing efforts of the federal government supporting education at all levels, with particular emphasis on science, mathematics, engineering, and technology.

REPORTS

The President's Council of Advisors on Science and Technology has produced reports on a variety of science policy topics. Copies of the following reports may be obtained free of charge from the Office of Science and Technology Policy, Executive Office of the President, Washington, D.C. 20506; (202) 395-4692.

Achieving the Promise of the Bioscience Revolution: The Role of the Federal Government
Daniel Nathans, Chairman

High Performance Computing and Communications Panel Report
Solomon Buchsbaum, Chairman

LEARNING to Meet the Science and Technology Challenge
Peter Likins, Co-chairman
Charles Drake, Co-chairman

Megaprojects in the Sciences
John McTague, Chairman

Renewing the Promise: Research-Intensive Universities and the Nation
David Packard, Chairman
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Science, Technology, and National Security
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Technology and the American Standard of Living
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