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ABSTRACT

Prepared by the National Science Foundation and the Department of Education in response to a request by President Carter for information on the condition of science and engineering education in America, this document contains data showing a decline in the general understanding of science and technology among secondary school students. Although scientific and technical literacy are increasingly necessary in our society, high school students are dropping out of science and mathematics courses after the tenth grade, resulting in a citizenry lacking understanding of the increasingly technically complex world. While data from econometric projections indicate that, with a few exceptions, there should be adequate numbers of engineers and scientists at all degree levels to fill available positions in 1980, concern also needs to be given to the education of engineers, scientists, and technicians. Suggestions for actions to alleviate these and related problems and to refocus efforts for upgrading education for the citizen as well as for the specialist are included in this report. Positive action is needed so that all citizens have the scientific and technical understanding to participate in an increasingly complex society and so that technical and professional personnel remain on the cutting edge of scientific and technical progress. (PB)

SCIENCE AND ENGINEERING EDUCATION

FOR THE 1980s AND BEYOND

Prepared by the

National Science Foundation

and the

Department of Education

October 1980

THE WHITE HOUSE

WASHINGTON

October 14, 1980

During the past three years, the President has mounted a vigorous effort to respond to challenges in energy, in health, in agriculture, in protection of the environment, in national security and the quest for peace, and in the renewal of our industrial base and economic productivity. In the years ahead, science and engineering will play an important role in meeting these challenges, and our public policy decisions will increasingly involve issues of a technical nature.

In keeping with the Administration's commitment to insure our country's future strength, the President asked the Secretary of Education and the Director of the National Science Foundation to examine the adequacy of science and engineering education for the Nation's long-term needs. Their report, "Science and Engineering Education for the 1980's and Beyond," provides a thoughtful analysis of a number of important and difficult issues facing the Nation's science and engineering education systems.

Several of the issues the report raises have already been partially addressed by the Administration as part of the recently-announced economic revitalization package. In addition to initiating reforms in the tax system to stimulate investment and spur growth, the President has pledged additional funding for scientific research and technological development over the next two years. These funds will sustain 3% real growth in basic research in each of these years, as well as a range of new projects to promote cooperation in research among government, industry, and the universities. In addition, the President's Economic Revitalization Board will establish a new partnership between business and government to improve the skills of the workforce. These measures, taken together, will do much to stimulate new interest in science and engineering careers and strengthen the research and training base of the nation -- the universities and engineering schools throughout the country.

As we consider the FY 1982 budget during the next several months, the Executive Office of the President will continue to work with the agencies to find specific ways to strengthen the education of our professional scientists, engineers, and technicians. The report notes that both the instructional and research capacities of our universities in several fields have been strained by faculty shortages and equipment obsolescence. We intend to enhance the capabilities of our science and engineering programs for education and for research.

The report also documents a decline in the general understanding of science and technology among the students in our secondary schools. Because we recognize that secondary education is primarily a function of our states and localities, the Department of Education, with assistance from the National Science Foundation, will hold a series of regional conferences of educators, scientists, and state and local officials to reflect on the report and to plot action, as appropriate, at all levels to improve the understanding of science and technology among our citizens. The process will insure that these groups are involved in shaping and implementing a response to the problems the report describes.

Our educational system is the key to maintaining our leadership position among the nations of the world. All of our citizens must have scientific and technical understanding to participate in an increasingly complex society, and our professional and technical personnel must remain on the cutting edge of scientific and technical progress. We congratulate Secretary of Education, Shirley Hufstedler, Acting National Science Foundation Director, Donald Langenberg, the former Director of the Foundation, Richard C. Atkinson, and all of those who helped develop this report for their dedication to these goals.

In releasing this report, we join with them and with our schools, state and local governments, colleges, universities, businesses, and industries, in a commitment to the highest quality scientific and technical education for all Americans.

Frank Press

Frank Press
Science and Technology
Advisor to the President

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PART ONE

REPORT TO THE

PRESIDENT OF THE UNITED STATES

Shirley M. Hufstedler
Secretary of Education

Donald N. Langenberg
Acting Director
National Science Foundation

Dear Mr. President:

Our response to the questions you posed in your February 8, 1980 memorandum on the condition of science and engineering education in this country has been divided into two components. The first of these examines the basic scientific and technological education of all our citizens; the second looks at professional science and engineering education. More detailed information about the issues we address appears in the attached analysis prepared by our staffs.

I. SCIENCE AND TECHNOLOGY EDUCATION FOR ALL AMERICANS

There is today a growing discrepancy between the science, mathematics, and technology education acquired by high school graduates who plan to follow scientific and engineering careers and those who do not. Scientific and technical literacy is increasingly necessary in our society, but the number of our young people who graduate from high school and college with only the most rudimentary notions of science, mathematics, and technology portends trouble in the decades ahead. Thomas Jefferson's axiom that an enlightened citizenry is the only safe repository of control over the ultimate processes of society surely includes the necessity for scientific and technological enlightenment. While students who plan scientific and engineering careers are receiving an adequate educational foundation, more students than ever before are dropping out of science and mathematics courses after the tenth grade, and this trend shows no signs of abating. This situation has several troubling implications:

o The role of science and technology is increasing throughout our society. In business, in government, in the military, in occupations and professions where it never before intruded, science is becoming a key to success. Today, people in a wide range of nonscientific and nonengineering occupations and professions must have a greater understanding of technology than at any time in our history. Yet our educational system does not now provide such understanding.

o Students who take no more mathematics and science after their tenth year in school have effectively eliminated, by the age of sixteen, the possibility of science or engineering as a career. The pool from which our future scientific and engineering personnel can be drawn is therefore in danger of becoming smaller, even as the need for such personnel is increasing.

o Education has long been the route by which upward mobility has been achieved by disadvantaged groups in our society. This verity has not changed. Increased emphasis must be given to aiding those who have been excluded, for too long, from careers in science and engineering. We stress this imperative both for reasons of equity and to increase the size of the pool of talent from which the Nation's scientists, engineers, and technicians can be drawn.

o The declining emphasis on science and mathematics in our school systems is in marked contrast to other industrialized countries. Japan, Germany, and the Soviet Union all provide rigorous training in science and mathematics for all their citizens. We fear a loss of our competitive edge.

The contribution of science and technology to our security and prosperity rests on two bases. The first of these is the competence and inventiveness of the practitioners, the scientists, and engineers who design and build the system. But the second base is equally important to our overall success as a Nation. This second base consists of the overwhelming portion of our population which has no direct involvement in science and technology, or with the science and engineering community. They are indirectly involved through their influence on the governmental and industrial sources of funding for scientific and technological endeavors. They are involved in the regulatory and policy decisions that set directions for scientific inquiry and technological development. They reap the benefits of science and technology. Many need some knowledge of science and technology to do their jobs well. However, the current trend toward virtual scientific and technological illiteracy, unless reversed, means that important national decisions involving science and technology will be made increasingly on the basis of ignorance and misunderstanding.

There has been, over the past fifteen years or so, a shrinking of our national commitment to excellence and international primacy in science, mathematics, and technology. This lessening of commitment has not been the result of a conscious decision on anyone's part, but it has nevertheless pervaded our society. The schools of this Nation are but reflections of the degree of national commitment in any area, and they therefore are not so much a cause of this condition as a result. To correct this debility, therefore, will require that attention be given not only to the schools themselves, but also to increasing public understanding and appreciation of the importance of excellence in these areas. We therefore propose a coordinated program which will: (a) increase public awareness of the need for excellence in science and technology, and (b) help the schools fulfill their role in formal science and technology education.

A. INCREASING PUBLIC AWARENESS OF THE NEED FOR EXCELLENCE IN SCIENCE AND TECHNOLOGY

A New National Commitment to Excellence in Science and Technology Education for All Americans

Since about 1970, there has been a nationwide trend toward reduction of high school graduation requirements. Only one-third of the Nation's 17,000 school districts require graduates to take more than one year of mathematics or science. At the same time--and we are not sure which came first--colleges and universities have reduced the amount of mathematics and science required for admission. These two trends are undoubtedly interrelated, and they are disturbing.

The current focus on "basic skills," which originated in an understandable concern about the quality of education, has also had an adverse impact. Science is not generally viewed as "basic," so its role is diminished in such programs, while the "basic" skill involved in mathematics is only simple computation. Problems arise when the acquisition of "basic skills" becomes the curriculum, rather than simply a foundation upon which students can build their ability to deal with more complex situations and problems. To help reverse this trend:

o You, with the advice of the Secretary of Education, the Director of the National Science Foundation, and leaders of other appropriate organizations, can create a President's Council on Excellence in Science and Technology Education. This Council could undertake an effort comparable to the President's Council on Physical Fitness and Sports, which, with a small budget, has had great influence during the past two decades. In particular, it could provide a vehicle for Presidential statements aimed at teachers' organizations, State and local school officials, and colleges and universities about the need to raise science and mathematics requirements for all secondary school students. It would also provide a means for giving Presidential recognition to those who have made significant contributions to excellence in both formal and informal scientific and technological education.

o You can convene a national conference of leaders in education, business, industry, the media, public interest groups, and private foundations. This conference would explore more effective linkages between formal and informal scientific and technological education, and would have as its objective an increased commitment by private enterprise to support excellence in scientific and technological education for all Americans. Such a commitment could be accomplished by such means as public service advertising, cooperative partnerships with schools, and support for the educational roles of public centers and parks. The National Science Foundation and the Department of Education are prepared to assist you in organizing such a conference.

Increasing Public Understanding of Science and Technology

While our primary concern is with the quality of science, mathematics, and technology being offered in the Nation's formal educational system, we are also distressed by the fact that the majority of adult Americans who have already passed through that system have received an education which is inadequate to their needs as citizens in today's technically complex world. For this reason, we believe that the initiatives we recommend to increase the amount and quality of scientific and technological education for all Americans must incorporate mechanisms to provide access for all citizens to scientific and technical information. This information should become part of the environment in which they live and in which they respond to the everyday problems they encounter. The success of these broad initiatives will depend on the cooperative and complementary activities of many sectors in our society, including business and industry, the Federal Government, State and local governments, community organizations, scientific and professional associations, and university and industrial scientists and engineers who engage in public service activities. To this end:

o A Federal Interagency Coordinating Committee on Public Understanding of Science and Technology can be established to include representatives of the major Federal scientific and technical agencies, with the National Science Foundation as the lead agency. The Committee would work in close coordination with the President's Council on Excellence in Science and Technology Education, and would be assigned the tasks of assessing existing Federal activities and developing goals, policies, and practices designed to maximize the effectiveness of the total Federal effort.

o Existing programs within the Department of Education and the National Science Foundation can be focused on encouraging and assisting two- and four-year colleges, universities, and other local educational organizations to provide a range of adult education courses aimed at increasing the public understanding of science and technology, especially in relation to local and regional issues of science- and technology-related public policy.

o The National Science Foundation can extend existing programs to permit science and technology museums, planetariums, zoos, nature centers, and parks to develop their capabilities to improve the public understanding of science and technology. Programs within the Department of Education which provide general support to museums, as well as those that offer support to public libraries, can be focused more sharply on public understanding of science and technology.

B. HELPING THE SCHOOLS

In addition to measures that are directed at society as a whole, we realize that specific programs must focus on schools, helping them do a better job of producing graduates who are prepared and equipped to assume their places in our technologically oriented society. To this end, we propose four courses of action aimed at improving the curriculum, introducing new technologies, helping teachers, and increasing awareness of, and preparation for, career opportunities in science and technology.

Curricula

Federally sponsored curriculum development programs were an important strategy for improving science and mathematics teaching in the post-Sputnik era, and there is persuasive evidence that these programs had a long-term, salutary effect. Today there is a need for similar programs, but the target group is different. While programs of the 1950s and 1960s were aimed at developing textbooks for future science and engineering majors, today's desperate need is for curricula for students who are not interested in professional scientific and engineering careers. There is a great mismatch between the content of secondary school science and mathematics courses and the needs and interests of students for whom these courses will constitute their entire formal scientific education. With few exceptions, these courses are not directed toward personal or societal problems involving science and technology; nor do they offer any insight into what engineers and scientists do; nor do they have vocational relevance except for the chosen few.

New curricula could provide students with a better basis for understanding and dealing with the science and technology they encounter as citizens, workers, and private individuals. By stimulating interest in science and technology, they can also motivate students to take science and mathematics courses beyond tenth grade, thereby preserving their options to enter science and engineering careers. The development of new curriculum materials, as well as the dissemination and use of existing materials that speak to the needs and interests of the broad spectrum of students, would incorporate the last twenty years of experience in achieving constructive change in our schools. To this end:

o New teaching materials in science and technology can be developed for the broad spectrum of elementary and secondary students, with special emphasis on the special needs of minorities, women, and the physically handicapped. This is especially important for students in the middle and junior high schools. These curriculum materials could focus on the science and technology basis of essential national problems such as energy, natural resources, and health. The National Science Foundation can build on existing activities to involve outstanding scientists, mathematicians, and engineers in the enterprise, while the Department of Education can take the lead in involving educators, and in helping school systems implement new courses and teaching approaches.

Electronic Technologies

The school curriculum rarely considers the role of the computer in our society. Just as we recognize the Stone Age and the Bronze Age, the Iron Age and the Machine Age, historians are likely to look back on our own time and label it the "Computer Age." Use of computers and other modern electronic technologies has far outstripped the most venturesome predictions of twenty years ago. The computer is revolutionizing the way business and industry are conducted, and thus the nature of many jobs. The small calculator is ubiquitous, appearing even in the hands of kindergarten children. Examination of school curricula, however, would, by and large, offer little evidence of the existence of this electronic revolution. There is a yet unanswered need for our educational system to prepare students to understand and use the new electronic aids to the human mind.

The convergence of computer and communications technologies not only creates new educational needs, but also provides new possibilities for addressing existing needs. Hand calculators, computers, television, and new video recording technology can provide:

a. Opportunities for assessing the existing science and mathematics curricula at all levels, taking advantage of possibilities for new organizations of subject matter, new applications, alternative teaching strategies, stronger interrelationships among different fields of study, and a better connection of science and mathematics with the future needs of students;

b. Individualized, interactive instruction in science, mathematics, and engineering for students at all levels, ranging from drill and practice to the simulation of complex problem situations;

c. Increased motivation for both students and teachers. Most students are familiar with the use of hand calculators, and in the near future many can be expected to become familiar with micro-computers through out-of-school activities. The incorporation of these technologies into teaching can integrate school work in science and technology with common experiences of students, and can be used to provide individualized challenges to students with different needs and interests;

d. Inexpensive and more individualized diagnostic and performance testing that is more sophisticated than presently used multiple choice techniques.

To make better use of modern electronics technologies in education:

o The National Science Foundation can build on existing programs to challenge scientists, mathematicians, and engineers to develop detailed strategies and devise the needed software to exploit modern electronics in education, while the Department of Education can take the lead in helping schools learn how to use the new technologies.

o Since computers have come to exemplify the pervasiveness of technology, they provide a useful point of departure to grasp the significance, for society, of the full range of modern technology. The Department of Education and the National Science Foundation, working with schools, colleges and universities, and industry, can support the development of curricula which contribute to a better understanding of that significance.

Teachers

Recent studies confirm that the classroom teacher still plays the pivotal role in education. Thus, it is distressing to learn that there is a serious shortage of mathematics and physical science teachers in the Nation's secondary schools. In the case of mathematics teachers, the annual vacancy rate may run as high as ten percent nationwide, and five-year projections do not indicate likely improvement in this situation. Equally disconcerting, however, is the fact that many of these vacancies do not really go unfilled. The jobs instead are given to individuals with only marginal capability in these teaching areas. As might be expected, the quality of instruction then frequently declines. The most likely cause of this teacher shortage, in contrast to a personnel surplus in other teaching fields, is the growing disparity between salaries inside and outside of education. During 1978-79, for example, a person with a bachelor's degree in mathematics or statistics could expect to receive only three-quarters as much as a teacher as he or she could receive from private industry.

A second factor underlying the declining quality of secondary-level education is a lack of suitable classroom laboratory facilities, while a decline in Federal support for faculty development is a third factor.

Finally, support systems for teachers are eroding. There are relatively few persons available outside the classroom to provide quality control and assist teachers with pedagogical problems. And continuing educational opportunities for mathematics and science teachers have been reduced. Our Nation has a tradition of local sovereignty over school systems. We firmly believe that this decentralized approach to education is the key to maintaining the strength and diversity in our Nation's schools. Nevertheless, in some areas the prestige of the President and the resources of the Federal Government can and should assist local school systems. We believe it is important that the actions outlined be conducted in consultation and partnership with States and local schools. To this end:

o Several existing Department of Education programs that speak to the needs of teachers can be focused more sharply on science, technology, and mathematics instruction. The programs include the Teacher Corps, Teachers' Centers, and the National Diffusion Network which, taken together, can provide special resources and assistance in course preparation and in resolving substantive day-to-day problems encountered in teaching science, mathematics, and technology. These programs also offer superior teachers opportunities to share insights with their less experienced colleagues both locally and throughout the Nation.

o The Department of Education can establish regional centers jointly with State and local governments and private industry to make scientific and technological equipment, including personal computers, available to schools. Such a program would build on experience gained during implementation of the school equipment provision of the National Defense Education Act.

o The National Science Foundation can build on its long experience to support in-service and summer institute programs and short courses to introduce experienced science and mathematics teachers at all levels to new curricula and the uses of computer and communications technology and to upgrade the skills of less qualified teachers. Such programs could be supported jointly by industry and could offer teachers experience in industrial settings as well as in universities.

o Communities can be encouraged and assisted to use resources available in local industry, colleges and universities, libraries, museums, planetariums, zoos and nature centers, and parks to enrich scientific and technological education. The National Science Foundation can support the development of strategies to use such resources effectively, while the Department of Education can provide schools with funds to gain access to them.

C. INCREASED AWARENESS OF PREPARATION FOR CAREER OPPORTUNITIES IN SCIENCE AND TECHNOLOGY

There is persuasive evidence that many students today are simply not aware of the career opportunities which exist in scientific and technological fields. Many of them apparently have the misconception that the only people in these fields are those with advanced degrees and that if they are not top academic students, they need not apply. This is particularly true of women and minority group members, who are grossly underrepresented in scientific and technical fields. To help correct these misconceptions, we make the following recommendations:

o The Department of Education's Vocational Education Program can assist schools in introducing into vocational courses material emphasizing the occupational opportunities available to secondary school graduates with good qualifications in science, mathematics, and technology.

o The National Science Foundation, in cooperation with industry and through an expanded program of in-service and summer institutes and short courses, can develop programs to make secondary school science and mathematics teachers more aware of the range of occupational and professional positions that require adequate preparation in mathematics and science.

o The National Science Foundation and the Department of Education can expand existing programs to provide adequate career information to minority and female students, beginning in their early adolescent years.

o The National Science Foundation and the Department of Education can undertake a special joint effort to encourage secondary school students to take more mathematics and thus broaden the career options available to them on graduation. Such an effort will require that NSF support the development of mathematics courses which provide a reasonable grounding in algebra and an introduction to probability and statistics to a broad range of students. It will also require the Department of Education to encourage the introduction of such courses into the schools.

o The National Science Foundation, in cooperation with the Department of Education, can extend existing programs which aim to identify, during their early adolescent years, students with special talent for science and mathematics and offer them opportunities to develop their interest in these areas. Such programs could include summer workshops in community and industrial settings coupled with follow-up activities in the schools. They could also include support for science and mathematics courses in high schools that State or local officials have singled out as being especially dedicated to the pursuit of excellence.

Together, these measures form a comprehensive approach to the need to strengthen the Nation's science and engineering capabilities. They are not a panacea, but we believe they can go a long way toward reversing the decline in national commitment to excellence in science, mathematics, and technology.

II. PROFESSIONAL EDUCATION FOR ENGINEERS, SCIENTISTS, AND TECHNICIANS

The second part of this summary and analysis is concerned with the professional education of scientists, engineers, and technicians.

The economic well being, security, and health and safety of Americans during the remaining two decades of this century, and beyond, will depend increasingly on our ability as a Nation to strengthen our technological and scientific enterprise. Several other countries are challenging our leadership in science and technology. During the coming decades, we are likely to be confronted with increasing competition, both from already industrialized countries and from those newly emerging industrialized countries with enormous labor resources. The United States cannot compete successfully in this environment unless it strengthens its technological base. This, in turn, will require that the Nation have sufficient numbers of engineers, scientists, and technicians with the skills and training required to meet present and future challenges, and that we make effective use of those skilled personnel.

Whether this Nation will choose to embark on a new commitment to the education and effective utilization of professional engineers, scientists, and technicians is critically important to answering the questions implicit in your February 8 memorandum. The attached staff analysis summarizes the results of several different econometric projections, which indicate that, with a few exceptions, there should be adequate numbers of engineers and scientists at all degree levels to fill available positions in 1990--provided we assume that the Nation does nothing different in the future in the ways it trains and makes use of engineers and scientists to address national problems. Since the technological complexity of our society is almost certain to increase, however, we believe that taking that assumption as a given would not be in the best interests of the Nation. Indeed, the one factor most likely to increase the ratio of economic growth to employment would be an increase in productivity. Such an increase will surely come, if at all, from better trained people devising new ways to use scientific and technical knowledge, and from a society that is better prepared to assimilate technology. We also believe that the ability of engineers, scientists, and technicians to exploit new opportunities and meet new demands will be more important to the Nation's future than their absolute numbers. Moreover, it is our judgment that the Nation can only benefit from having greater numbers of persons with degrees in science, engineering, and technology employed in occupations that are not directly related to science and technology. Thus, we believe that the Nation can ill afford an attitude of complacency regarding the education and utilization of professional engineers and scientists.

We also believe that the need to have a scientific and engineering work force of the highest possible quality is consistent with an important social goal. Women, minorities, and the physically handicapped are presently underrepresented in engineering and science. Thus, programs which aim to increase the participation of these groups will also increase the pool of talent from which the Nation's future engineers and scientists will be drawn.

The attached staff analysis identifies and describes a number of current and emerging problems associated with professional education. In our judgment, four of these having to do primarily with the education of engineers and computer professionals are particularly pressing. The following is a discussion of each of these four problems, together with recommendations for appropriate Federal actions. While these recommendations focus primarily on engineering and the computer professions, we believe they are also applicable to problems emerging in professional science education that, while less urgent today, are likely to b come severe unless appropriate actions are taken.

A. RELIEVING SHORT-TERM PERSONNEL SHORTAGES

Shortages of trained personnel presently exist in the computer professions, chemical engineering, electrical engineering, and industrial engineering, as well as most other fields of engineering. Spot shortages are also reported in several subdisciplines of the physical and biological sciences. It is our judgment that there are likely to be presently unpredictable shortages in other subfields in the future. While market forces may ultimately relieve current and future shortages, we believe that the innovative capacity of American industry will be severely hampered in the interim. We simply cannot afford to wait for the slow workings of the marketplace.

We recommend that:

1. The National Science Foundation, in cooperation with the Department of Defense, the Department of Energy, and the Department of Education, and other agencies that anticipate personnel shortages in fields in which they have specific concerns, can provide support to colleges and universities to

develop special one- and two-year programs that would allow qualified undergraduates to transfer from their original course of study in a scientific or engineering field to a related course of study in a field where significant personnel shortages exist or are projected.

2. The National Science Foundation, the Department of Energy, and other mission agencies, in cooperation with industry, can offer post-graduate industrial traineeships in selected fields where there are current or projected shortages at advanced degree levels. These programs can focus special attention on identifying qualified minority, women, and physically handicapped candidates. Advantage should be taken of the National Institutes of Health medical traineeship experience in designing such programs.

3. The effectiveness of Federal intervention in the engineering and scientific labor market will depend in large measure on the reliability of personnel projections. For this reason the Bureau of Labor Statistics, the National Science Foundation, and the National Center for Education Statistics should be encouraged to pursue their efforts to improve their projection methodologies. We also recommend that all Federal agencies and the Office of Management and Budget be required to submit personnel projection estimates for all major research and development initiatives. Results of such personnel projections should be disseminated in a form that will be useful to employers, other Federal agencies,

universities, and students who need information about career options.

B. STRENGTHENING EDUCATIONAL CAPACITY IN THE ENGINEERING AND COMPUTER FIELDS

There are, today, severe shortages of qualified faculty members in most fields of engineering, as well as in the computer professions. Industries have expanded their research and development efforts and have increased the rate at which new, sophisticated products are introduced. To effect this, they are luring faculty members away from the universities into challenging well-paid positions. At the same time, they are making such attractive job offers to bachelor's degree recipients that many who would once have gone to graduate school now opt for positions in industry. The net effect has been a reduction in the ability of universities to provide education in engineering and the computer professions, although undergraduate demand for these areas is more intense than ever. Unless the problem of faculty erosion is alleviated, it is possible that many engineering schools and departments that educate computer professionals may have to reduce their enrollments during this decade, thereby reducing the numbers of trained people in these fields that the Nation's future requires.

Several factors in addition to noncompetitive salaries contribute to the problem of attracting and retaining qualified faculty members. The attraction of being able to work with graduate students and conduct research in an atmosphere of academic freedom has been tarnished of late by difficulties in obtaining research support, problems of inadequate equipment and facilities, and the instability of government funding for research. Additionally, the current shortage of graduate students and faculty members creates unusually heavy teaching loads which make academic jobs less attractive for those interested in research. We believe, therefore, that the faculty erosion problem can be alleviated in part by improving both the research and teaching environment in engineering schools and computer departments.

An important additional problem in engineering education is a severe lack of the equipment required for instructional purposes at the undergraduate level. During the past decade, computer-aided design and computer-assisted manufacturing methods have provided important gains in productivity for some large companies in this country. The apparatus required to teach these methods to students, however, is generally unavailable in engineering schools. Consequently, a good deal of the instruction being offered may in fact be obsolete. While this situation may not pose an insurmountable problem for a large employer who can afford on-the-job training for new personnel, it can have deleterious effects on smaller companies and industries which have traditionally depended upon new graduates for information about the latest developments in engineering practice.

While there can be important Federal contributions toward alleviating the shortage of engineering and computer professional faculty, we believe that universities and industries must assume the primary role in this area. Universities increasingly recognize the special research needs of their engineering and computer professional faculties. Some are considering the appropriateness of a medical school model for engineering schools, whereby faculty members would be allowed more liberty to supplement their salaries and gain access to specialized research facilities in industry. Industry also can take several steps to respond to the shortage of faculty. It can, for example, form consortia to support university research groups; or offer money, equipment, and personnel in exchange for university-conducted research. It can make its unique research facilities available to university faculty. Industry can provide support to universities which would in turn offer continuing education to its engineers. It can offer cooperative arrangements so that university faculty members can engage in industrial research while industrial engineers serve in university departments.

Finally, industry can join with universities to create work-study programs at undergraduate, graduate, and post-doctoral levels.

Since the instructional equipment problem arises in part from the changing requirements of industry, we believe that it can also be addressed through closer cooperation between industry and engineering schools. Such cooperative efforts should continue to be the primary focus, but we believe that some direct, short-term Federal assistance to engineering schools is also required.

We recommend that:

1. The National Science Foundation, in cooperation with the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration (NASA), and other mission-oriented agencies, provide greater support for the

purchase of research equipment in university departments of engineering and computer science. Such equipment would permit faculty to engage in research aimed at advancing the state-of-the-art in these fields. The National Science Foundation can also extend its present support for the purchase of equipment for undergraduate engineering instruction, and the Department of Education can institute a similar, coordinated instructional equipment purchase program. Funds for research and instructional equipment would be given on the basis of individual proposals relating equipment needs to plans for carrying out high-quality research and instruction.

2. The enrollment of women in engineering schools has increased dramatically during the past five years. In order to exploit this pool of talent, the National Science Foundation can extend existing programs to assist female engineering students to pursue their studies beyond the undergraduate level, and, in particular, to explore the possibility of university careers.

3. The National Science Foundation and other Federal agencies that support research in universities can expand existing pilot programs to reduce the administrative burden of grant and contract management and expand access of university faculty and graduate students to sophisticated, state-of-the-art research facilities. Such programs include the NSF

master grants, regional equipment centers, and joint university-industry research efforts.

4. The National Science Foundation can develop incentives aimed at encouraging students in graduate engineering and computer programs to enter university teaching. These incentives could be in the form of fellowships for Ph.D. candidates who plan to go into teaching. NSF can also expand its research initiation program for new engineering and computer faculty by providing such faculty with special research grants of two- or three-year duration.

5. The Department of Defense, the Department of Energy, NASA, and other Federal agencies that support research relevant to their missions can provide incentives to engineering and computer faculty and graduate students through salary, traineeship, and facilities support, as indicated by agency assessment of needs.

6. The effects of tax, patent, copyright, and antitrust laws on industrial contributions to university engineering research and instruction should be recognized. We are aware that the effects of those laws and regulations on industrial research and development are currently being examined as one result of the recent Domestic Policy Review on Industrial Innovation. It is clear to us that any steps that improve the environment for industrial research and development will also have a direct, positive effect on research and teaching in

engineering schools. In particular, there is evidence that such laws and regulations have created barriers to industrial support of engineering and computer science education. If it were possible to modify Federal policy in these areas without sacrificing the social benefits that the laws and regulations are intended to provide, it would do much to cement university-industry relations and promote private support of education and research.

C. COORDINATING CONTINUING EDUCATION ACTIVITIES

Continuing education and retraining are essential in science and engineering, where technical advance is constantly creating new knowledge and new fields and opportunities. At present, continuing education of industrial engineers and scientists is spread among a variety of sources, including private entrepreneurs, industrial firms, professional societies, and colleges and universities, with little or no coordination. We believe that the responsibility for providing continuing education and retraining for industrial engineers and scientists should be the responsibility of these private sector organizations. However, the Federal Government can help coordinate such individual efforts and can also help universities adjust to changing demographic and economic conditions by expanding their capacity for continuing education.

We recommend that:

1. The National Science Foundation conduct a survey of continuing education needs of technology-intensive industries and convene a conference, based on the results of the survey, of university continuing education directors and industry representatives. The objective of the survey and conference would be to stimulate better coordination in developing continuing education programs in the universities.

2. The National Science Foundation periodically assemble and disseminate a registry of continuing education programs for industrial engineers and scientists.

3. The National Science Foundation give special emphasis to the development of continuing education programs which aim to retrain qualified female engineers and scientists who dropped out of the labor force.

D. ASSESSING THE STATUS OF TECHNICIAN TRAINING

The success of technologically related enterprises in this country depends to a large degree on the number and quality of skilled technicians who provide support for our professional scientists and engineers. Other industrialized countries, including West Germany, Japan, and the Soviet Union, place heavy emphasis on training technicians in special vocational schools. These societies not only offer technicians good jobs, but also considerable social status as well. By way of contrast, technician training in the United States has largely been a haphazard enterprise, accomplished through a combination of on-the-job training, a few technical institutes, and vocational training in secondary schools. In addition, a substantial fraction of the technicians in this country were trained in our armed forces in high-grade, very high-cost, educational programs. Recently, two-year community colleges have begun to play an important role in technical training. We believe that these institutions need to be integrated into the overall science and engineering education system so they can improve their effectiveness in attracting and training the technicians needed to ensure our future success as a technological society. However, we and our staffs have concluded that our primary immediate need is for an improved information base on technicians and their training.

We recommend that:

1. The National Science Foundation conduct a comprehensive survey of industry to obtain data about technician needs, training, and utilization, and that information regularly collected by the Bureau of Census and Bureau of Labor Statistics be examined to determine its quantity and quality. The results of these surveys can be used to determine what types of data on technicians ought to be collected, analyzed, and disseminated on a routine basis.

2. The National Science Foundation and the Department of Education organize a series of regional conferences to assess the needs of technology-based indust-y for skilled

technicians and the state-of-the-art in training them. These conferences would bring together representatives of community colleges and local industry, as well as experts in the training and utilization of technicians from the Department of Defense.

3. The Department of Education, working with the States, utilize vocational education to encourage minority candidates to undertake training to qualify as skilled technicians in technology-intensive industries.

E. A CONTINUING REVIEW STRATEGY

We believe that these four sets of recommendations, if adopted, will do a great deal to solve the most pressing current problems associated with professional engineering and science education. But we also believe that a strategy is needed that will continuously review the adequacy of our science and engineering education and periodically renew momentum for identifying and attacking emerging problems.

We recommend that:

An independent forum be established with the objectives of watching over the broad set of relationships between the Federal Government and the college and university science and engineering education system, and of guiding the evolution of these relationships in directions that assure their strength and vitality. Such a forum would provide a setting where individuals and representatives of various interests could address major policy issues and problems.

In order to explore the feasibility of this idea, the National Science Foundation can award a contract to a private educational association to develop a detailed plan and identify appropriate sources of support, and also provide some start-up funds for staff and travel. However, the feasibility of the forum must obviously depend in large measure on the willingness of nonfederal organizations to provide it with continuing support.

Shirley M. Hufstedler
Secretary of Education

Donald N. Langenberg
Acting Director
National Science Foundation

August 15, 1980

STAFF ANALYSIS

Prepared by the

National Science Foundation

and the

Department of Education

EXECUTIVE SUMMARY

A. BACKGROUND

This analysis has been prepared for use by the Director of the National Science Foundation and the Secretary of Education in preparing a response to President Carter's February 8, 1980, request to them for an assessment of the adequacy of the country's science and engineering education for our long-term needs.[1/] The President's request is consistent with the concerns, goals, and policies set forth in his Science and Technology Message to the Congress in March 1979. These concerns, goals, and policies involve the continuing availability of adequate supplies of energy, food, and natural resource supplies; uses of space; national security; industrial innovation and economic growth; promotion of better health; improvement of government regulatory processes; building bridges between countries; and understanding the fundamental forces of nature. Other Administration initiatives, including the Domestic Policy Review on Industrial Innovation (whose results were announced in a special Presidential Message of October 1979) and its three annual budget messages also emphasize relationships of science, technology, and our long-term needs.

These Administration documents and initiatives recognize that the Nation's scientific and technological enterprise can maintain high levels of achievement and that an educated citizenry will choose to deploy science and technology to solve national problems. But such achievements and choices will depend on the levels of scientific and technical understanding and performance of people in a broad range of occupations and professions and on the ability of all Americans to function in a society that is being transformed by science and technology. Behind achievements and performance lie the availability and effective use of sufficient numbers of well-trained scientists, engineers, and teachers of science and engineering at all educational levels.

B. SCOPE AND METHOD

Two broad sets of issues are addressed in the review:

1. The quantitative and qualitative adequacy of professional scientists and engineers at all degree levels, now and in 1990; and

2. The capacity of our educational system at different levels to provide good scientific and technical education and training for all Americans, including those who do not intend to pursue the scientific and engineering professions.

Information bearing on these issues was obtained from a wide range of sources in addition to the published literature. These sources included: current science and engineering educational and occupational data collected by the Bureau of Labor Statistics (BLS), the National Center for Educational Statistics (NCES), and the National Science Foundation (NSF): information on the state of science and engineering education in the Nation's secondary schools, colleges, and universities collected by the Department of Education and the National Science Foundation; assessments of trends and needs contributed by the Departments of Agriculture, Defense, and Energy, the National Aeronautics and Space Administration, and the National Institutes of Health; data and perspectives submitted by professional scientific, engineering, and educational organizations; papers by individual specialists commissioned by the National Research Council and preliminary proceedings of a series of seminars based on those papers; and several rounds of review of draft materials carried out by experts in the education, business, and government sectors.

This review of current problems and issues in science and engineering education does not address some important subjects that, while related to the review, are beyond its scope. These include:

a. The explicit derivation and specification of alternative long-term social, economic, and technological needs for our country and their detailed discussion and prioritization;

b. The issues, options, and necessary improvements in areas other than science and engineering education;

c. The analyses of advantages and disadvantages of the many current and possible future specific programs to improve science and engineering education.

The last subject is particularly important and an assumption of this review is that the relevant Federal agencies (including the National Science Foundation and the Department of Education), along with non-Federal organizations, will proceed quickly to provide such specific analyses based upon the broader issues and findings presented here.

In addition, it should be noted that while the statements in this review pertaining to secondary school education and college and university enrollments are generally appropriate to the life sciences, it is not intended to include a full and complete assessment of personnel needs and training requirements for biomedical and behavioral research. Such assessments are carried out by a Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel under the National Research Council, Commission on Human Resources, of the National Academy of Sciences.

The next two sections summarize the findings of this review. Section C summarizes the principal broad issues that have emerged; Section D discusses those issues in more detail under five headings: (1) Professional Engineers, Computer Professionals, and Their Education; (2) Scientists and Their Education; (3) Additional Components of the Post-Secondary Science and Engineering Education System; (4) The Science and Engineering Teaching Professions; and (5) Science and Mathematics Qualifications of Secondary School Graduates.

C. PRINCIPAL FINDINGS

The most important set of issues, problems, and opportunities that emerges from this review relates to the need to improve the quality and amount of science, mathematics, and engineering education provided to U.S. students. A significant number of the findings and options discussed below, and in the body of this review, address this more general finding.

1. There are, at present, shortages of trained computer professionals and most types of engineers at all degree levels. In contrast, the current supply of scientists is adequate to satisfy existing demand for their service, except in a few subfields of physical and biological science (Section II-A).

2. Projections indicate that in 1990 the aggregate number of new science graduates at all degree levels should exceed the number able to find jobs in the broad fields in which they are trained (Section II-B). With the possible exception of a few subfields, the numbers of new engineering baccalaureates should, by 1990, be adequate to satisfy projected demand for their services. However, the adequacy of Ph.D. engineers in 1990 is problematic. The current shortage of trained computer professionals at all degree levels is expected to persist beyond 1990 (Sections II-B and C).

3. While considerable progress has been made in increasing the representation of minorities, women, and the physically handicapped, all three groups continue to be underrepresented in the science and engineering professions. The number of women in engineering schools has been increasing rapidly, and they now compose about 15 percent of freshman enrollments. With this exception, the proportion of minorities and women who major in science and engineering is still small relative to their proportion among college students (Appendix C).

4. There is an immediate problem of providing for the acquisition, retention, and maintenance of high-quality faculty to teach engineering and

computer courses. This problem is the result of several factors, including rapidly increasing undergraduate enrollments, decreasing Ph.D. output, a widening gap between academic and nonacademic salaries, and the obsolescence of facilities and technical resources needed for research (Sections II-A and III-B).

5. The high cost of maintaining existing laboratory apparatus and of replacing obsolete apparatus and facilities is a severe problem for university faculty who engage in research in equipment-intensive fields such as electrical engineering, computer science, physics, chemistry, and the life sciences. In some cases instruments needed to carry out research at the frontiers of these fields are available only at centralized facilities, and this situation is affecting the education of advanced graduate students (Section III-C).

6. Although industrial design and engineering practices have changed rapidly under the impact of modern electronic technology, engineering schools, in general, lack sufficient resources to modernize teaching facilities and equipment, with the result that many new engineers and computer professionals are not adequately trained in state-of-the-art techniques (Section III-B).

7. Decreasing priority is being given to science and mathematics in secondary schools (Section V-B and C). This situation is in marked contrast to Germany, Japan, and the Soviet Union, which have been pursuing a policy of more extensive and rigorous education in science and mathematics for all citizens (Appendix B). While the qualifications

of U.S. secondary school graduates who intend to pursue college majors in science and engineering remain high (Section II-D), the general quality of science and mathematics instruction at the secondary level has deteriorated since the 1960s, as has the scientific and mathematical competence of students who are not motivated toward careers in science and engineering (Section V-B).

8. At both the secondary and higher education levels, there is a serious problem of reduced educational standards and requirements. Inadequate attention is paid to motivating and providing an appropriate education in science and technology for those who do not intend to pursue science and engineering as careers but who need an understanding of them for their work and in their lives (Sections III-D and IV-E). A shortage of mathematics and science teachers and the absence of adequate teacher support resources at the secondary level hampers the ability of the schools to provide science and mathematics instruction for those not likely to follow science and engineering careers (Section V-D).

9. There is a noticeable absence of coordination among the various components of the science and engineering education system, particularly between the secondary and the college and university levels. This lack of coordination is evidenced, for example, by: (a) reduced opportunities for sustained interactions between university and secondary school science and mathematics faculties (Sections V-D and E); (b) the insufficient attention paid to the special problems of two-year community colleges which are assuming an increasing share of the responsibility for training the Nation's skilled technical work force (Section IV-A); and (c) the

dispersion of the responsibility for continuing education among many types of providers and the isolation of continuing education from the formal educational system (Section IV-B).

10. Media which focus attention on science and technology, including newspapers, magazines, public radio and television, science and technology museums, and related institutions enjoy considerable popularity among nonscientists and nonengineers. However, these media have not been systematically exploited as adjuncts to the formal education system (Section IV-C).

D. DETAILED FINDINGS

Additional details of these findings by broad field and level of educational system follow:

The Education of Engineers and Computer Professionals

Several indicators point to current shortages of engineers and computer professionals at all degree levels. These indicators are consistent with anecdotal information from industry and the Federal Government concerning difficulties in attracting sufficient numbers of engineers. In addition, the Department of Defense reports problems in retaining engineers. Reduced levels of engineering graduate school enrollments in recent years and the large share of those enrollments accounted for by foreign nationals (approximately one-third to one-half of whom ultimately return to their own countries) are creating particular difficulties in filling current positions at the Ph.D. level (Section II-A).

Quantitative projections carried out by the Bureau of Labor Statistics (BLS), the National Center for Educational Statistics (NCES), and the National Science Foundation (NSF) indicate that by 1990 there will be an ample supply of new bachelor's level engineers in most fields of engineering, reflecting continuing strong increases in undergraduate engineering enrollments. These projections appear to be in essential agreement with sectoral projections based on several different future energy scenarios. However, there is some question about whether the supply of Ph.D. engineers in 1990, particularly in energy research and development areas, will be adequate. The number of computer professionals at all degree levels, is likely to be insufficient to fill available positions in 1990 (Section II-B).

Engineering schools and computer departments are experiencing difficulty in attracting qualified junior faculty and retaining senior faculty members. If the universities continue to compete on unfavorable terms for Ph.D. engineers, the capacity of the educational system to produce well-trained engineers and computer professionals at the undergraduate and graduate levels will be severely strained, perhaps limiting the validity of the personnel projection results summarized in the preceding paragraph (Section III-B).

Faculty shortages, coupled with increasing undergraduate enrollments, have already led to class sizes that are, in the opinion of the American Society for Engineering Education, too large for effective teaching. Many senior engineering and computer faculty have had to expand their teaching commitments and limit their research activities that have traditionally been a principal asset of the U.S. system and also an important attraction of academic employment. This situation is exacerbated by the obsolescence of laboratory research apparatus and physical facilities in many university engineering schools (Section III-B).

Design and production engineering in industry have changed dramatically due to the ready availability of sophisticated computer-assisted and automated systems. Few engineering schools, however, have had sufficient resources to modernize their teaching facilities and equipment. As one result, many new graduates are not well trained relative to current practices in large firms. This situation could affect the productivity and competitiveness of small- and medium-sized companies that have traditionally counted on new employees to keep them abreast of the latest state-of-the-art in engineering practice (Section III-B).

Scientists and Their Education

There are currently enough trained scientists in all broad fields and at all degree levels for science-related employment, and this situation is likely to persist through the decade. However, current spot shortages are reported in several subfields of the physical and life sciences, particularly at the Ph.D. level. These subfields include solid state physics, plasma physics, optics, polymer chemistry, analytical chemistry, and toxicology (Sections II-A and B).

Academic positions for new Ph.D. scientists will remain scarce in most fields, and thus there may be several basic research fields in which potential scientific advance will be retarded. There is no consensus about the effects of the resultant phenomenon of aging faculty on the quality of research and science teaching at the university level. However, the lack of "new blood" in many science departments reduces the ability of educational institutions to benefit from innovative approaches to instruction and research (Section III-C).

Rising costs will continue to strain the capacity of many U.S. colleges and universities to provide high-quality training in science both for undergraduate and graduate students. In addition, the rapidly rising costs of research and the obsolescence of research equipment and facilities will make it difficult for all but the premier university science departments to maintain the close coupling between research and teaching that has traditionally characterized the education of Ph.D. scientists in the United States. Knowledgeable people in other industrialized countries have frequently cited this association as an important U.S. advantage (Section III-C).

Many more undergraduates major in science than enter careers directly related to science. In addition, the desirability for nonscience majors to pursue more science at the college level is widely acknowledged. However, insufficient attention has been paid to the needs of students who do not intend to pursue graduate work in science (Section III-D).

Additional Components of the Post-Secondary Science and Engineering Education System

Two-year community colleges, the fastest growing component of the higher educational system, are assuming a large part of the responsibility for the training of technicians that formerly was carried out almost entirely on the job. These institutions have a potentially important role to play in improving the technical capability of the U.S. work force and in increasing the productivity of engineers and scientists. The scientific and engineering community, however, has focused relatively little attention on their problems (which include increasing competition with four-year colleges for a share of a decreasing student-age population and reduced levels of local support), or on opportunities to integrate them more effectively into the engineering and science educational system (Section IV-A).

Continuing education serves several purposes, particularly for industrial engineers and scientists: upgrading the skills of technicians to that of bachelor's degree level engineers, allowing mid-career engineers to earn Ph.D.'s, and updating and broadening the skills of engineers and scientists to qualify for positions in related fields or in nonscience and nonengineering jobs. Although data are fragmentary, significant numbers of scientists and engineers take advantage of continuing education opportunities. However it remains dispersed among many types of providers, with industry assuming a disproportionate share of the responsibility for providing it (Section IV-B).

The desire of an appreciable fraction of the nonscientific and nonengineering public to maintain some contact with developments in science and technology and their relationships with society is evidenced by the popularity of media presentations that focus on science and technology. These media include newspapers, magazines, public radio and television, science and technology museums, and related institutions such as planetariums, zoos, nature centers and parks. Little is known about the extent to which exposure to such informal science and technology educational opportunities leads to any genuine comprehension. Nor have these media been exploited systematically as adjuncts to the formal education system (Section IV-C).

Status of the Science and Mathematics Teaching Professions

At the secondary school level, there is a pronounced national shortage of competent mathematics teachers. A random national survey of mathematics supervisors during the 1977-78 school year revealed that almost 10 percent of mathematics teaching positions were vacant and that shortages were even more severe in some regions of the country. Since four years of secondary school mathematics are prerequisite for virtually all college science and engineering majors, overcoming the shortage of qualified mathematics teachers is an urgent problem. There is a similar though apparently less severe shortage of new physical science teachers. These shortages indicate that the secondary schools may lack the capacity to prepare students to pursue college majors in science and engineering. Perhaps more seriously, teacher shortages hamper the ability of schools to provide suitable instruction in science and mathematics for those who are not likely to pursue science and engineering careers (Sections II-A, V-D).

Undersupplies of mathematics and science teachers persist despite the fact that there are ample numbers of people with bachelor's and master's degrees in mathematics and the physical sciences. Teacher shortages in these fields may reflect an overall sharp decrease in education majors.

No doubt they also result from relatively poor salaries and other disincentives, as well as from widespread public indifference to the status of teachers. In addition, teachers have few opportunities to renew or enhance their familiarity with developments in their fields or enjoy sustained interactions with colleagues in universities and industry (Section V-D).

The conditions under which secondary school teachers work in many schools have deteriorated due to several factors: rising costs, increasing taxpayer resistance to providing them with salary increases and adequate support, and lack of motivation on the part of many students. The financial factors coupled with declining enrollments have had particularly adverse effects on science and mathematics education because they have led to cutbacks in equipment and facilities that are so important to teaching these subjects. Likewise, funds to hire special resource persons for science and mathematics teaching have all but vanished over the last decade. Many schools have eliminated or reduced the laboratory portions of school science courses because equipment has become obsolete or inoperative. Paraprofessional personnel to set up and maintain equipment are generally unavailable. Schools seem to make little effective use of science museums, planetariums, zoos, nature centers, parks, and similar informal educational facilities, despite their availability and popularity in many communities (Section V-D).

<u>Science and Mathematics Qualifications of Secondary School Graduates</u>

Only about one-sixth of all secondary school students currently take junior- and senior-year courses in science and mathematics. A large percentage of this group intends to pursue careers in science and engineering or in the health-related professions. This percentage has remained approximately constant for several years. Judged on the basis of nationwide test scores administered to high school seniors, the qualifications of those intent on careers in science and engineering remain high (Section II-D).

Few students who are not intent on such careers pursue science beyond 10th grade biology or mathematics beyond 10th grade geometry. This situation has resulted in part because colleges have relaxed their entrance requirements and also because few States require additional courses. Thus, in effect, at the age of 16 (or earlier) many students deny themselves the opportunity to enter rigorous college level courses in science and engineering at the beginning of their careers. The dropout rate from science and mathematics at the 10th grade level is particularly severe for girls and for minority students (Section V-B).

There appear to be several reasons for these declining participation rates, including low levels of achievements in science and mathematics required for graduation in most states, the reduction of college entrance requirements and a narrowing of school curricula to a focus on "basics," and a serious mismatch between most existing curricula and the interests and needs of those students who do not intend to pursue careers in science and engineering. Most secondary school science courses focus on the structure of the academic discipline. Little of vocational relevance is presented in such courses, and there is virtually no exposure to technology. The potential for using modern electronic technology to reassess science and mathematics teaching at all levels does not appear to have been widely recognized or exploited (Sections V-C and V-E).

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REFERENCE

1. The text of President Carter's February 8, 1980 memorandum addressed to the Secretary of Education and the Director, National Science Foundation, follows:

> I am increasingly concerned whether our science and engineering education is adequate, both in quality and in numbers of graduates, for our long-term needs. Accordingly, I would like you to carry out a review of our science and engineering education policies at the secondary and university levels to ensure that we are taking measures which will preserve our national strength. Please submit a report to me, with your recommendations, by July 1, 1980.

The original July 1 submission date was later advanced to August 15 at the suggestion of the Director of the Office of Science and Technology Policy.

SECTION I. INTRODUCTION

A. BACKGROUND: SCIENCE AND ENGINEERING EDUCATION IN AMERICAN SOCIETY

Science and technology have deep roots in our national history. The founders of the American Republic regarded them as integral components of the society they sought to establish. More than three decades before the American Revolution, Benjamin Franklin and his colleagues emphasized the importance they attached to these pursuits when they organized the American Philosophical Society to cultivate "all philosophical experiments that let light into the nature of things, tend to increase the power of man over matter. and multiply the conveniences and pleasures of life."[1]

Thanks in part to the combination of vision and practicality exemplified by people like Franklin, the centrality of science and technology to American life is now an almost universally recognized fact, rather than a dimly perceived ideal. The Federal Government itself has come to play a pivotal role in encouraging and pursuing the search for scientific knowledge and the application of that knowledge to the service of human needs. President Carter's March 1979 Science and Technology Message to the Congress provided a detailed summary of both immediate and long-term national goals and needs that have significant scientific and technological dimensions, and explored the responsibility of the Federal Government in achieving them. These needs and goals involve the continuing availability of adequate supplies of energy, food, and natural resource supplies; uses of space; national security; industrial innovation and economic growth; promotion of better health; improvement of government regulatory processes; building bridges between countries; and understanding the fundamental forces of nature. Other Administration initiatives, including the Domestic Policy Review on Industrial Innovation whose results were announced in October 1979, and the Administration's three budget initiatives also focus sharply on the relationships of science, technology, and national needs.

Given the centrality of science and technology to American life, it is almost self-evident that the Nation's future prosperity and security will continue to depend in large measure on whether it has, and will continue to have, sufficient numbers of adequately trained scientists, engineers, and technicians, and whether it utilizes them effectively.

In the early years of our national life, the pursuit of science and technology was the province of a handful of serious amateurs who cultivated them as intense leisure-time activities. Today, without exception, many years of rigorous training starting at the secondary school level are required to become a scientist or engineer. For this reason, the Nation's schools, colleges, and universities must be regarded as important components of its science and technology base. Their strength and continued ability to attract and to provide a high quality education to sufficient numbers of highly motivated science and engineering students are vital national concerns.

However, the responsibilities of the Nation's science and engineering education system go considerably beyond preparing students for careers in those professions. Our schools, colleges, and universities also have the responsibility to provide a basic understanding of science and technology to those who do not plan to pursue careers in those areas. Enormous advances in our scientific knowledge have occurred since World War II. Technological developments have increased the complexity of our society and resulted in changes undreamed as recently as 20 years ago. As a result, many occupational and professional pursuits that formerly had little scientific or technical content now require a reasonable level of competence in those areas. The pace of scientific and technological change is certain to persist and lead to additional complexities. Moreover, trends external to science and technology, such as changing American demographic patterns, the continuing shift toward a service-oriented economy, and the changing relationships between this country and the rest of the world will almost certainly alter our national life during the remaining years of the century in ways that cannot be fully anticipated. What is certain, however, is that science and technology will become even more central than they are today, and thus that a deeper understanding of science and technology will become increeasingly important to the ability of all Americans to function in their occupations and professions and in their roles as citizens. Therefore, the question of whether science and engineering education is adequate for the Nation's long-term needs must consider the adequacy of education for all Americans, not simply for the relatively small number who intend to pursue science and engineering as professions.

President Carter's Science and Technology Message recognized these broader aspects of the connections between science, technology, and American society by emphasizing the Federal Government's concern with the overall public understanding of science. This view of science and technology as part of the very fabric of our society was also central to the vision of Franklin and his colleagues. Thus, national recognition of the importance of scientific and technological capability and understanding at all levels is not only essential to our future. It is in the best traditions of our Nation.

b. FEDERAL SUPPORT FOR SCIENCE AND ENGINEERING EDUCATION: HISTORICAL NOTES

Many organizations and institutions are involved in the support and provision of science and engineering education and in making effective use of the people who are trained in science and engineering: private and public universities, community colleges, primary and secondary schoo' , State and local governments, professional scientific and engineering societies, private industry, and, of course, the Federal Government. The Federal role in science and engineering education, though limited, has become crucial.

Since World War II, the Federal Government's support for science and engineering education has been regarded as an integral component of its science and technology policy. The mode and extent of Federal support has changed over the years with changing perceptions of the significance of science and technology to national goals and needs.

During the final months of World War II, President Roosevelt asked Vannevar Bush, Director of the Office of Scientific Research and

Development, to examine several aspects of the U.S. scientific research system, one of which was the adequacy of the educational system for discovering and developing scientific talent. In his classic report, Science - The Endless Frontier, Bush, assisted by four distinguished committees, made several recommendations, two of which were to lay the foundation for Federal support for science and engineering education.[2]

First, the report recommended that the Federal Government support basic research in American universities--and thus, indirectly, science and engineering faculty and graduate students.

Second, and more directly, it identified a need to increase the flow of talented students into scientific careers and make up the deficits of a war which had diverted nearly an entire generation of science students into the armed forces. Thus the Bush report for the first time established the development of scientific talent as a Federal responsibility. It recommended that the Federal Government establish a series of graduate fellowships and undergraduate scholarships for science students and a program to identify and develop the talents of science-oriented servicemen and veterans. Although the undergraduate scholarships were never instituted, Science - The Endless Frontier firmly established the principle of government assistance to further the education of talented students in areas related to national needs.

While basic research in the universities was supported by several Federal agencies in the late 1940s, graduate and post-doctoral fellowship support for science and engineering students was initiated only after the establishment of the National Science Foundation (NSF) in 1950. During most of its first decade, providing such support to students who had already made a commitment to professional careers remained NSF's primary science education support function. However, beginning in the mid-1950s, NSF also turned its attention to the need to increase the pool from which future scientists and engineers would be drawn. A dual strategy was pursued to this end: (a) teacher training institutes to develop the knowledge and skills of those who would, in turn, teach promising students; and (b) curriculum development to improve the quality and content of science and mathematics instruction in secondary schools.

While these programs were established before the launching of Sputnik I in October 1957, public alarm over that Soviet achievement resulted in increased budget appropriations that transformed plans and experiments--for teacher education and curriculum development--into programs. In January 1958, President Eisenhower stressed the importance of education to national security and called for special attention to education in science and technology. NSF's budget for science education was substantially increased. Through the National Defense Education Act (NDEA) of 1958, new programs for science education were established in the Office of Education in Department of Health, Education, and Welfare. NDEA made funds available to local school systems through State Departments of Education for remodeling facilities on a minor scale and for purchasing equipment and modern teaching aids for both science and mathematics. The Act also provided support to the States to employ supervisors in each of these fields. In addition, the statutory authority of NSF was amended to enable it to support science, mathematics, and engineering education programs <u>at</u>

all levels [emphasis added]. The potential for overlap and replication between the Office of Education and the National Science Foundation, particularly at the precollege level, was resolved by the understanding that NSF would deal exclusively with science and engineering, operate mainly through scientific societies, science departments of colleges and universities, and individual scientists, while the Office of Education would operate mainly through State and local school systems.[3/] The division of responsibility was reaffirmed legislatively in 1979 in the Act creating the Department of Education.

Between 1959 and 1962, three successive reports on science and engineering education, issued by the President's Science Advisory Committee (PSAC) recommended an expanded role in these areas for the Federal Government.[4/] Education for the Age of Science, released in May 1959, recognized the stakes and the responsibilities of all participants in American science and engineering education: secondary schools, technical institutes, and colleges and universities; industry and private foundations; local and State governments; and the Federal Government. The four tasks set forth by the report were:

o To build well-rounded curricula and in each subject to stress intellectual content and provide for recognition of intellectual achievement;

o To recognize that teaching is a task of primary importance in modern society and therefore to encourage, aid, and reward competent teachers in all fields;

o To recognize that our modern society needs human talents of a wide variety, and that it is essential that every individual be given the maximum opportunity to develop his or her particular talents to their utmost;

o To understand that the advances of science and technology need special attention to the end that (1) all citizens of modern society acquire reasonable understanding of these subjects, and that (2) those with special talents in these fields have full opportunity to develop such talents.

A few of the problems cited in this report have been ameliorated by the adoption of its recommendations. But many, including science and mathematics teacher shortages, the lack of science literacy in the general population, the need to define the role of technicians, and the difficulty of attracting faculty for engineering schools, still remain.

In November 1960, another PSAC panel, under the guidance of Glenn T. Seaborg, produced Scientific Progress, the Universities, and the Federal Government. Its central theme was that the U.S. needed "more scientists, better trained, with finer facilities." The Seaborg Committee operated from the premise that "basic research and graduate education, together, are the knotted core of American science, and they will grow stronger together, or not at all." Therefore, the report called for Federal support for new centers of excellence, modernization of research facilities and equipment, fellowships for doctoral candidates, and better coordination of Federal programs affecting university research.

The Seaborg Report was followed, in 1962, by Meeting Manpower Needs in Science and Technology (Edwin R. Gilliland, Chairman), which concluded that "unless remedial action is taken promptly, future needs for superior engineers, mathematicians, and physical scientists will seriously outstrip the supply." This report was ambitious in several respects: it was the first of the education reports to attempt to forecast science and engineering personnel supplies and formulate policy from the predictions. Based on projections of engineering, mathematics, and physical sciences doctoral awards, the report set a "national goal" of 7500 Ph.D. awards annually in these areas by 1970. This goal for annual Ph.D. production was actually exceeded by 25 percent. In addition, the report envisioned a greatly expanded Federal role in graduate training in engineering, mathematics, and physical sciences, calling for the Federal Government to support up to 60 percent of the Nation's efforts in graduate education in these fields through student support, construction and equipment grants, and other funds to institutions to cover the costs of graduate education and to develop new centers of excellence.

The momentum generated by the shock of Sputnik began to wane in the late 1960s. By 1969 the United States had succeeded in putting a man on the Moon, an achievement that may have convinced many Americans that the Nation's supremacy in science and technology could thenceforth be taken as a given. Meanwhile, the Nation turned more attention to the social goals of providing equal access to education at all levels for the disadvantaged and underrepresented--particularly minorities and women, and, later, the physically handicapped. During the 1970s, the Office of Education furthered these goals by channeling funds directly to the States, while the

National Science Foundation expanded its responsibilities to provide support to individual minority, women, and physically handicapped science and engineering students and to qualifying institutions.

Beginning in 1968, real-dollar Federal investments in research and development and in science education began to decline, in part because the war in Vietnam was placing heavy pressures on the controllable parts of the Federal budget. These declines, coupled with demographic changes, marked an end to the period of rapid expansion of university science and engineering departments in the U.S. Federal support for graduate fellowships in science and engineering also declined sharply from 1968 onward, while support for teacher training institutes and curriculum development dropped off sharply starting in the early 1970s and then virtually disappeared.

Federal research and development investments began to increase once again in 1975, signalling a revival of concern for the health of the Nation's science and technology enterprise. This concern was made more explicit in several previously referred to Presidential messages and actions. At the same time the conviction grew in many quarters that the educational gains that had followed in the wake of Sputnik had not been sustained. Given the historical importance of the Federal role in supporting science and engineering education; given that our science and engineering education system is an integral component of our science and technology base; given that the overall quality of that base is of vital national significance, it became essential to inquire, once again, whether the Nation's science and engineering education is--and is likely to remain--adequate to our long-term needs.

C. PRESENT AND FUTURE CONCERNS

When the Seaborg and Gilleland Reports were issued in the early 1960s, the Nation worried about whether it had enough trained scientists and engineers.[5/] The focus was on quantity. As a result of these concerns, Federal programs were aimed toward increasing the supply of scientists and engineers. There were also concerns about quality, but they related primarily to the problems of identifying and nurturing the most talented students for careers in these fields.

Today the problems of science and engineering education are more subtle than they were two decades ago. Present concerns go beyond whether we now have enough engineers and scientists and are likely to have enough in the near-term future. These concerns include the ability of the scientific and engineering workforce to perform effectively, the amount and quality of education in science, mathematics, and technology being provided to those who will never become scientists and engineers, and the ability of the many components of our educational system to maintain and improve the quality of scientific and technical education at all levels and for a broad spectrum of students in the face of economic pressures, obsolete and inadequate facilities, reduced enrollments in many fields, and severe faculty shortages in others.

This review addresses two sets of issues:

1. Whether there are, and are likely to be in the near-term future, adequate numbers of professional engineers and scientists; and

2. Whether the various components of the Nation's educational system are presently providing--and have the capacity to provide--adequate education in science, engineering, and technology to a broad spectrum of students at all levels.

Data and information that speak to these issues have been collected from a wide range of sources and analyzed under four headings:

- Supply and Demand for Science and Engineering Personnel;
- Science and Engineering Education at Four-Year Colleges and Universities;
- Additional Components of Post-Secondary School Science and Engineering Education; and
- Science and Mathematics Education at the Secondary School Level.

Appendices that draw together information on International Comparisons of Science and Engineering Education (Appendix B) and on Minorities, Women, and the Physically Handicapped in Science and Engineering (Appendix C), as well as Technical Notes (Appendix A), notes on contributions to the review (Appendices D and E), and a selected bibliography (Appendix F) are also included.

Although the role of the Federal Government may well be crucial to the resolution of many of the problems that are identified in this review, that role must remain a limited one. Certainly Federal actions are unlikely to be effective unless they are taken in coordination with actions on the part of other organizations and institutions that are involved in the support and provision of science and engineering education at all levels, and in those that employ people who are receiving an education in these areas. This need for coordination is particularly essential for addressing the most severe problems associated with science and engineering education, few of which will admit to short-term, isolated solutions.

In addition to providing information on which Federal options can be considered, the Department of Education and the National Science Foundation hope that this review will catalyze other organizations and institutions to consider appropriate steps to improve science and engineering education in the United States.

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SECTION II. SUPPLY AND DEMAND FOR SCIENCE AND ENGINEERING PERSONNEL

Judged from an economic perspective, the Nation's science and engineering labor force can be defined as being adequate at any given time if there are enough trained personnel in all occupational specialties and at all degree levels to produce the goods and services demanded by society. Alternatively, we could attempt to derive science and engineering personnel requirements by defining a set of social objectives, regardless of whether those objectives were currently revealed in the marketplace for goods and services. Such sets of social objectives might require that our society use scientific and engineering personnel in ways that are quite different than at present. One could then explore options for direct or indirect Federal intervention to create actual jobs for the requisite number and mix of scientists and engineers. However, there are a large number of combinations of social objectives and no unique, value-free way to select one combination as being superior to all others. To define national needs in terms of alternative social objectives therefore implies a set of value judgments that would have to be imposed on society and would be inappropriate for particular Federal agencies to make. For this reason, this section assesses the quantitative adequacy of the Nation's science and engineering labor force, now and for the next decade, relative to the jobs that currently exist in various science and engineering specialties, and the number that are likely to be created by the market, given Federal decisions being made now to increase defense expenditures, to create a synthetic fuels industry, and to balance the budget. These projections _do not_ consider the effects on employment of the emergence of new technologies which can offer more efficient ways to produce existing goods and services or introduce new goods and services into the economy.

A. CURRENT BALANCES BETWEEN SUPPLY AND DEMAND

Summary of Current Situation

Four types of indicators were examined to assess the current relative balance between the supply of and demand for various occupational categories of science and engineering personnel: (a) unemployment rates; (b) judgments by employers of the difficulty of filling job vacancies; (c) changes in relative salaries for new entrants into particular fields; and (d) the mobility of personnel within science and engineering fields and between science and engineering and other fields. The first two indicators measure static conditions at a particular time. The latter two reflect adjustments made by the market to correct personnel shortages and surpluses.

An assessment of current market conditions for science and engineering personnel based on these sets of indicators appears later in this section. Taken together with additional information submitted for this review, they lead to the following conclusions:

- There are current shortages of computer professionals at all degree levels and tight markets* at all degree levels in most engineering fields.

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* Throughout this section the terms "tight market" and "strong market" are used to indicate that employers have difficulties finding qualified applicants to fill existing job openings.

o University engineering schools and schools and departments which train computer professionals are unable to fill existing doctoral faculty positions, a condition that reflects the strong industrial market in these fields. Moreover, the American Society of Engineering Education reports that engineering and computer departments are also experiencing difficulties in retaining both their junior and senior faculty.[1/] In contrast, openings for Ph.D.'s in the academic sector are scarce in all fields of the mathematical, physical, biological, and social sciences.

o Employers in the industrial sector report that there are more than enough qualified physicists, chemists, mathematicians, and biologists. Trends in mobility data, however, suggest that the demand for chemists may be increasing faster than the supply. Despite the adequacy of personnel in these broad fields, spot shortages (particularly at the Ph.D. level) are reported in several subspecialties, notably solid-state and plasma physics, optics, analytical and polymer chemistry, and toxicology.[2/]

o The Department of Defense reports problems in recruiting and retaining both civilian and military engineers because of the generally superior career opportunities in nonmilitary employment.

o Many secondary schools report vacancies for teachers in mathematics and the physical sciences, despite ample supplies of people with bachelor's and master's degrees in these fields[3/] (Section V-D).

1. Unemployment Rates[1]

Only about 1.5 percent of the 2.5 million scientists and engineers in the 1978 labor force were unemployed, as compared to 6.0 percent unemployment for the total civilian workforce.[4/] The lower level for science and engineering workers reflects their high degree of training relative to the remainder of the workforce as well as intense activity in the Nation's science and engineering enterprise. The very tight market for computer professionals was evident in an estimated unemployment rate of only 0.3 percent. By themselves, very low unemployment rates are evidence more of the general employability of scientists and engineers than of generalized shortages. Other information is needed to identify fields with insufficent supplies.

2. Reported Job Openings

NSF staff have asked employers of scientists and engineers about the difficulty they have experienced in filling job vacancies. In mid-1979, 27 large industrial companies and research laboratories responded to an NSF survey on this subject. All industrial employers who reported about engineers and computer professionals said that both categories were in short supply. Supporting evidence of shortages of engineers came from the Engineering Manpower Commission,[5/] the College Placement Council,[6/] and the National Research Council.[7/] The U.S. Department of Labor's designation of several engineering subfields as "hard-to-fill occupations" also indicates shortages. Employers in the industrial sector indicated generally ample supplies of physicists, biologists, chemists, and

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mathematicians, though (as already noted) spot shortages are reported in several subspecialties.[8/]

In correspondence with representatives of schools of engineering and departments of computer science in 1979, NSF staff have found widespread expressions of severe difficulty in finding doctoral faculty. The large numbers of vacancies reflect not only the generally tight markets in these fields, but also the disadvantage of universities in competing with industrial employers who pay much higher salaries and who frequently offer superior facilities and research support to doctoral engineers and computer professionals. Contributing to the shortages of engineering faculty was a drop in doctoral awards in this field of 25 percent (3338 to 2494) between 1973 and 1979. In the latter year, approximately one-third of the new Ph.D.'s were nonimmigrant foreign students.[9/]

Short papers contributed by several Federal agencies for this study contained similar reports of the tight market for engineers. In the defense agencies, problems in recruiting and retaining both civilian and military engineers are aggravated by low entering salaries, low promotion rates, and often outmoded facilities for research and development. The Department of Energy stresses the need for engineers, particularly at the advanced degree level, to carry out research and develc ment for the Nation's synthetic fuel program (Appendix D-4).

Two indicators--changing relative salaries (3. below) and patterns of mobility between fields of training and fields of employment (4. below)

--provide evidence of the adjustments made by labor markets to alleviate shortages and surpluses.

3. Salary Data

Economic theory predicts that salaries in a field with shortages, or high demand, will rise relative to salaries in nonshortage fields. Salaries for new employees are more flexible than are those for experienced workers and, therefore, reflect changes in market conditions more closely. From 1974 through 1979, according to data from the College Placement Council, starting salaries for baccalaureate computer professionals and chemical, electrical, and mechanical engineers rose from 53 to 58 percent as compared to 37 and 42 percent rises for bachelor's degree holders in business and the humanities, respectively.[10/] These data also indicated a 51 percent increase in salaries for mathematics and chemistry baccalaureates and a 41 percent increase for those with degrees in biology, 38 percent for the social sciences, and 33 percent for the agricultural sciences.

4. Field Mobility Measures

Many new graduates, at all degree levels, choose to enter fields different from those in which they were educated. Such mobility across disciplines reflects market conditions in the chosen field of employment relative to the field of training as well as personal preferences. The ratio of the number of science and engineering graduates who enter the labor force in a particular field to the number earning degrees in the same discipline is an indicator of that field's balance between the supply of graduates and the demand for new workers, as well as the ease of transferring between fields. By this measure, there has been a marked shortage of degree recipients in the computer professions.

An NSF survey found that there were 2.7 times as many 1977 baccalaureates working in the computer professions in 1979 as had earned bachelor's degrees in that field two years earlier.[11/] At the master's degree level, the ratio was 1.6. These figures are the result of many 1977 science and engineering graduates in other fields switching to exploit superior job opportunities in the computer profession. (These two figures as well as those below were adjusted to exclude those engaged in full-time graduate study in 1979.) In engineering and chemistry, the corresponding ratios were all near 1, indicating strong markets in those two fields. By contrast, the following pairs of ratios for bachelor's and master's recipients were found in other fields: physics, .3 and .3; mathematical sciences, .2 and .4; environmental sciences, .5 and .8; biology, .3 and .6; psychology, .1 and .5; and economics, .2 and .6. (In these other fields, a master's degree is often the minimum educational requirement so the very low ratios at the baccalaureate level may overstate the relative lack of attractive job opportunities.) At the doctoral level, the most marked field switching has been to the computer professions. In 1979, about 3.5 times as many Ph.D.'s worked as computer professionals as had ever earned degrees in the field. The largest relative exodus occurred from physics and astronomy, which had only about 70 percent as many working in those fields as had earned degrees in them.

B. PROJECTED SUPPLY AND DEMAND FOR SCIENTISTS AND ENGINEERS IN 1990

Projections of the future balance between the supply of and demand for scientists and engineers point out those fields in which shortages of science and engineering personnel may prevent the U.S. from meeting important national goals. If projections indicate potential shortages, a decision can be made about whether the Federal Government should intervene to prevent the projected shortfall. Because of the length of time required to train scientists and engineers, efforts to increase supply can only have an effect after several years--hence the need to anticipate shortages well before they occur.

Summary of Projections

The projections described below indicate that in 1990 the supply of scientists and engineers at all degree levels will likely be more than adequate to meet demand in all fields except the computer professions, statistics, and some fields of engineering. These projections are summarized in Table I.

In general, the number of new science graduates should widely exceed the number who will be able to find jobs in the disciplines in which they were trained. The projected excess of graduates over jobs implies many with science degrees will take employment not directly related to science and engineering. Also implied is a continued upgrading of the level of training of the technical labor force. Baccalaureates would fill jobs once held by high school graduates and doctorates would fill positions formerly held by those with less training, often in positions unrelated to teaching or research and development.

These projections indicate that for engineers with bachelor's or master's degrees, the labor market in 1990 should be less tight than at any time since the early 1970s as a result of faster expansion in the supply of qualified personnel than in demand for their services. Employers may have difficulty, however, in finding graduates in some fields of engineering, such as aeronautical and industrial, particularly if defense programs expand rapidly.

Two sets of projections, one prepared by the Bureau of Labor Statistics, the other by the National Science Foundation, differ as to whether in the future there will be an ample supply or a shortage of doctoral engineers.

Some general limitations of all supply/demand projections are discussed in Section II-C (below). None of these is believed to invalidate the key projection findings summarized in Table I. However, it is worth noting at the outset that the supply projections (discussed in detail below and in Appendix A) assume that colleges and universities will have the capacity to educate all students at both the undergraduate and graduate levels who want to obtain degrees in a particular field of science or engineering and who are judged by those institutions to be qualified to do so. Several critics have suggested that this assumption may be unwarranted for engineering colleges. They point to several factors discussed in more detail in Section III-B--rising undergraduate enrollments, falling

TABLE I

PROJECTED MARKET FOR SCIENTISTS AND ENGINEERS IN 1990
BY FIELD AND LEVEL OF TRAINING
(all scenarios)

	BACCALAUREATES AND MASTERS	DOCTORATES
Physical Sciences	Adequate	Adequate
Atmospheric	Balance	
Chemical	Adequate	
Geological	Adequate	
Physics and Astronomy	Adequate	
Engineering	Adequate	Uncertain
Aeronautical	Balance-Shortage 1/	(Possible shortages some fields)
Chemical	Adequate	
Civil	Adequate	
Electrical	Adequate	
Industrial	Shortage	
Mechanical	Adequate	
Metallurgical	Adequate	
Mining	Adequate	
Petroleum	Balance	
Other	Adequate	
Mathematical Sciences	Adequate	Adequate
Mathematicians	Adequate	
Statisticians	Shortage	
Computer Professions	Shortage	Shortage
Life Sciences	Adequate	Adequate
Agricultural	Adequate	Adequate
Biological	Adequate	Adequate
Social Sciences	Adequate	Adequate
Psychologists	Adequate	
Other	Adequate	
All Fields	Adequate	Adequate

NOTE: "Adequate" indicates that projected supply exceeds projected demand.
"Balance" indicates that projected supply is close to projected demand.
"Shortage" indicates that projected supply is less than projected demand.
"Uncertain" is used for doctoral engineers because NSF projects an adequate supply in 1990 whereas BLS projects a shortage in 1985.

1/ Shortage under expanded defense spending assumption only.

Sources: Bureau of Labor Statistics, National Center for Education Statistics, and National Science Foundation.

levels of Ph.D. production, and faculty shortages--to indicate that these colleges may not be able to train all qualified applicants.[12/] In this case there would be fewer engineers available in 1990 than the projections indicate, possibly resulting in continuing tight markets in most specialties and, perhaps, serious personnel shortages in a few of them.

Projected 1990 Supply and Utilization of Scientists and Engineers

With the combined efforts of three agencies--the National Science Foundation (NSF), the Bureau of Labor Statistics (BLS), and the National Center for Education Statistics (NCES)--projections have been prepared of the supply and employment of all scientists and engineers in 1990. In recognition of the leadership provided by PH.D.'s in teaching, research, and management, additional projections describe possible conditions in the 1990 science and engineering doctoral labor market.

1. All Scientists and Engineers

The Bureau of Labor Statistics has developed two sets of projections of the demand for scientists and engineers at all degree levels in 1990. These projections (a Technical Note in Appendix A describes BLS projection methods) were carried out in a series of steps linking expected aggregate economic activity to output by industry to employment by occupation. BLS produced the first, or baseline, set of projections in 1979. These projections start with a set of assumptions covering the nature of economic conditions and Federal policy goals during the 1980s. These assumptions include a decline in unemployment to 4.5 percent by 1990 and an annual increase in labor productivity to 2.4 percent by 1985-1990 above the current rate. The policy goals in the baseline projections do not include (1) a sharply augmented defense budget; (2) large-scale development of synthetic fuels; or (3) a balanced Federal budget.

To assess the sensitivity of the baseline demand projections to alternative assumptions, BLS developed a set of alternative projections in which each of these three policy goals was included one at a time. This procedure allowed an estimation of the impact of each goal upon the utilization of scientists and engineers. These assumptions represent fairly extreme conditions. For example, the greatly expanded expenditures for defense would be in a scientific and technologically intense sector and would not be compensated for by decreased nondefense expenditures. It should be noted that these projections do not include scientists and engineers employed by secondary schools, colleges, and universities, since BLS does not project employment in educational institutions by field. The omission of academic employment in aggregate projections is mitigated by its inclusion in the projections of Ph.D. utilization (as described below), since Ph.D.'s account for a large majority of those employed in higher education.

Under the baseline assumption, BLS projects that the employment of scientists and engineers in science and engineering occupations and at all degree levels will grow by about 40 percent between 1978 and 1990. This growth would create about 180,000 new jobs in the mathematical, physical, life and social sciences, about 480,000 new jobs in the computer professions, and 250,000 new engineering jobs during the twelve-year period.* By far the most rapid growth, about 110 percent, is projected for computer professionals. Employment of all engineers combined is projected to grow by less than 25 percent, with the most rapid expansion for mining (almost 50 percent) and petroleum engineers (40 percent). Estimated growth in all other major subfields ranges between 19 and 28 percent. It should be noted that many computer professionals obtain their degrees from electrical engineering departments. If demand for these categories of computer professionals were combined with electrical engineering, employment in the latter specialty would be projected to grow at a much greater rate.

Among the sciences, growth is put at 40 percent for psychologists, geologists, statisticians, and economists. Occupations with projected slow growth include atmospheric scientists, physicists and astronomers, and mathematicians, all of which are projected at 10 percent or less.

Under the baseline assumption, defense expenditures (excluding compensation of military personnel) rise by 14 percent, or $6 billion in 1972 dollars, between 1978 and 1990. The assumption of a more rapid expansion of 43 percent, or $18 billion in 1972 dollars, has a small effect upon projected employment except for aeronautical engineers. Under this assumption, requirements for aeronautical engineeers would expand by about 40 percent over the twelve-year period, or double the baseline expansion.

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* New jobs created by growth plus openings for existing positions created by attrition of currently active workers equal total job openings reported in Table II.

To assess the possible impact of a second goal upon the science and engineering labor market in 1990, BLS, after consulting with the Department of Energy, devised a hypothetical program for the construction and operation of new facilities for coal liquefaction and gasification and oil shale development. The program, which is not intended to represent any official Administration proposal for synthetic fuels production, would produce about three quadrillion BTU's. This would be about 3 percent of the total energy supply, including imports, projected by BLS to be available in 1990, and equivalent to 1.4 million barrels of oil per day (MMBPD). In contrast, the recent House-Senate conference synthetic fuels bill sets a 1987 goal of 0.5 MMBPD and a 1992 target of 2.0 MMBPD.

BLS projections indicate that a synthetic fuels program of the scale analyzed would have only a very small effect upon science and engineering employment in 1990 and would not alter the market assessments made under the baseline projections. In assessing the effects of a large synthetic fuels program, BLS assumed that existing technology would be used in production facilities installed over the next ten years. As a result, most additional employment would be devoted to the construction and operation of new plants. These two activities require only limited numbers of scientists and engineers.

A final alternative projection assumes that the Federal budget will be in approximate balance by 1983 and will continue to be so through 1990. This is in contrast to the baseline assumption that the Federal budget will have a $32 billion deficit in 1980 that will decline to a $23 billion deficit in 1990. The alternative assumption of a balanced budget, achieved through higher taxes and lower expenditures, has no major effect upon projected 199C science and engineering employment, since the assumed changes in fiscal policy would affect the economy as a whole and have relatively little effect on those industries with high concentrations of scientists and engineers.

The demand for new science and engineering graduates between 1978 and 1990 was derived from estimates of 1990 employment. This demand would be for trained but inexperienced workers to replace experienced personnel who would die or retire and to fill the new jobs created in the twelve-year period. Under both the baseline and alternative assumptions, about 360,000 scientists and over one million computer professionals and engineers, or a total of about 1.4 million scientists and engineers would be needed to fill growth and replacement demand (excluding openings in academia). These estimates of employment openings by occupation are compared in Table II with projections by NCES of the supply of graduates at the baccalaureate and master's degree level through 1990 in each field. NCES projects that there will be about 3.4 million science and engineering baccalaureates and 630,000 science and engineering master's degrees awarded between 1978 and 1990 in the fields considered here. (A Technical Note in Appendix A describes NCES projection methods.)

Table II provides comparisons of BLS and NCES projections by field. These comparisons point to two fields with large deficits of people with bachelor's and master's degrees: the computer professions and statistics. Such gaps would be expected to attract large numbers f people with training in other fields, particularly mathematics, where degrees are

TABLE II

COMPARISONS OF PROJECTED JOB OPENINGS
WITH PROJECTED DEGREES IN SCIENCE AND ENGINEERING
1978-1990

	JOB OPENINGS, 1978-1990 (in thousands) Scenario				GRADUATES, 1978-1990 (in thousands) Level	
	BASELINE ASSUMPTIONS	ACCELERATED DEFENSE SPENDING	SYNTHETIC FUELS PROGRAM	BALANCED FEDERAL BUDGET	BACCA-LAUREATE DEGREES	MASTER'S DEGREES
LIFE AND PHYSICAL SCIENTISTS						
Agricultural	16	16	16	16	193	34
Atmospheric	5	5	5	5	5	4
Biological	38	38	38	37	637	78
Chemical	63	64	64	63	178	26
Geological	22	22	23	22	67	18
Marine	2	2	2	2	10	3
Physics and Astronomy	11	11	11	11	45	19
TOTAL	157	159	157	156	1,135	182
MATHEMATICAL SCIENCES						
Mathema-ticians	3	3	3	3	102	27
Statisti-cians	19	19	19	19	3	5
TOTAL	22	22	22	22	105	32
COMPUTER PROFES-SIONALS						
Programmers	300	302	300	299	NA	NA
Systems Analysts	221	223	221	221		
Other	28	29	28	28		
TOTAL	549	553	550	547	110	47
SOCIAL SCIENTISTS						
Psychol-ogists	76	76	76	75	490	111
Other	100	102	101	99	628	58
TOTAL	176	178	177	175	1,117	170

ENGINEERS						
Aeronautical	24	35	24	24	28	NA
Chemical	22	22	22	21	92	
Civil	95	95	95	94	134	
Electrical	121	128	121	120	172	
Industrial	94	98	94	93	48	
Mechanical	89	95	89	89	171	
Metallurgical	9	9	9	9	16	
Mining	7	7	7	7	11	
Petroleum	11	11	11	11	14	
Other	59	61	59	59	115	
TOTAL	528	561	534[2]	525	928[3]	196
TOTAL ALL FIELDS	1,432	1,473	1,439	1,424	3,395	626

1 Includes economists, political scientists, and sociologists.
2 Includes 4,000 engineers who are not distributed by field.
3 Includes 128,000 engineering technology degrees not distributed by field.

Note: Estimates of openings do not include academic employment. Detail may not add to totals because of rounding.

Sources: National Science Foundation, Bureau of Labor Statistics, and National Center for Education Statistics.

expected to be many times larger than job openings. Such inter-field mobility would continue the patterns of recent years. It is expected that such field-switching would prevent the emergence of a tight market for statisticians and would greatly diminish shortages of computer professionals. Other fields with large projected surpluses of graduates are agricultural sciences and natural resources, biology, physics and astronomy, psychology, and, as a group, the major social sciences. Baccalaureate chemists will also far outnumber jobs although supply may be fairly close to demand for master's degree holders in the field.

In all engineering fields, projected baccalaureates, including those in engineering technology, are almost 1.8 times the projected baseline openings. (Supply projections assume that engineering colleges will be able to expand enrollment significantly beyond current levels.) Under the baseline projections, only industrial engineers may have fewer graduates than openings. An accelerated defense program may push aeronautical engineers into a small 1990 deficit. Nuclear engineeers, a small subfield for which BLS did not prepare separate projections, may also have future shortages, according to the Department of Energy, because many universities have eliminated their nuclear engineering departments and more are scheduled to do so.[13/] Finally, since many new engineers are likely to continue to seek nonengineering jobs due to their own preference, the engineering labor market in 1990 may be tighter than the numbers in Table II would indicate.

A separate study supported by the Department of Agriculture considered current and future supply and demand in many occupations other than agricultural scientists (the only related occupation for which BLS and NCES projections have been compared here) for which agricultural or natural resources training may be required. The Agriculture study found that in 1985 there may be shortages of workers with training in several job categories such as agricultural engineering and food and agricultural chemistry.[14/]

2. Personnel Requirements under National Energy Scenarios

Several studies commissioned by the Federal Government have projected requirements for technical personnel under various national energy scenarios. Three studies have explored the personnel implications of large-scale programs to substitute synthetic fuels for imported oil and one has assessed the future adequacy of personnel supply in the coal mining industry. These studies are reviewed below.

a. The earliest and most comprehensive of the four studies was completed under an NSF contract in mid-1977 by the Center for Advanced Computation (CAC) at the University of Illinois. For this study, Scientific and Technical Personnel in Energy-Related Activities: Current Situation and Future Requirements, CAC combined their own highly disaggregated model of the energy sector with the BLS employment projection model. This allowed CAC to project requirements for scientists and engineers in 1980 and 1985 for the entire economy under three scenarios. This is in contrast to the other three energy-related studies which looked only at the energy-production sector. CAC describes the three scenarios as quoted below.

The Free Import Scenario assumes that energy consumption in the United States increases from the 1973 level of about 73 quadrillion Btu's to 99.1 quadrillion Btu's in 1985. Domestic energy production increases, but the growth of imports of oil and gas are substantial.

The Limited Imports Scenario assumes energy usage increases to 84.1 quadrillion Btu's in 1985. Domestic coal production increases substantially more than in Free Imports and nuclear power grows substantially more. Oil imports are much lower under Limited Imports.

The Synthetics Scenario uses the same major assumptions as the Limited Imports Scenario but in addition assumes a program of developing synthetic oil and gas that would produce a .9 MMBPD (million barrels per day) oil equivalent in 1985 and 1.8 MMBPD equivalent in 1990. The 1985 output is assumed to be .3 MMBPD of shale oil, .1 MMBPD of coal liquids, .3 MMBPD of high-Btu gas, and .3 MMBPD of low- and medium-Btu gas from coal (pp. 125-126).

CAC found that, for the economy as a whole, the three scenarios differed little in their requirements for scientists and engineers in 1985. Moreover, the differences were "in a direction that is counterintuitive." CAC found that the "Free Imports" scenario had slightly greater personnel requirements. CAC explained that "Free Imports" had the highest level of energy consumption of the three scenarios and hence the highest employment for energy production. This difference outweighed the higher construction employment under "Limited Imports" and "Synthetics" (p. viii). (It should be noted that Bechtel National, which prepared another study reviewed below, provided CAC the estimates of direct requirements for personnel for construction under the three scenarios.)

In 1979, the Department of Energy (DOE) commissioned four studies to assess the feasibility of a national program to produce 1.0 MMBPD of oil through coal liquefaction by 1990. For two studies, contractors, Bechtel National and UOP working with System Development Corporation (UOP/SDC), examined whether the lack of skilled manpower, particularly engineers, would impede meeting this goal. All four studies are summarized and presented as appendices in a March 14, 1980 TRW draft report to DOE: Achieving a Production Goal of 1 Million B/D of Coal Liquids by 1990.

Bechtel and UOP/SDC both assessed material and manpower requirements under current liquefaction technology. Bechtel analyzed engineering demand by subfield, chemical, mechanical, etc., whereas UOP/SDC examined all "technical manpower" together. Also, Bechtel considered requirements for both construction and operation of liquefaction plants whereas UOP/SDC, which was concerned with the chief potential impediments to meeting the synthetic fuels goal, examined only construction employment.

b. In Production of Synthetic Liquids from Coal: 1980-2000, Bechtel states that the supply of civil, electrical, industrial, and mechanical engineers "should be adequate" to meet the 1990 production goal (p. 4-8) although there could be major difficulties in sufficiently expanding the employment of chemical engineers. Bechtel calculates that the stated goal could require a peak of 1300 additional chemical engineers by 1984 (p. 4-4). For comparison, this would be about two to three percent of the 1978 stock of chemical engineers and about 13 percent of the latter who are engaged in "process design and construction work" (p. 4-7).

In evaluating the Bechtel findings, it is evident that coal liquefaction of one MMBPD by 1990 might cause some labor market adjustments. These might be reflected in such developments as experienced engineers being bid away from other jobs to the synthetic fuels program and in inexperienced graduates being asked to assume greater responsibilities more quickly than might normally be the case. Such adjustments, however, are clearly to be expected whenever any industry rapidly expands its level of production. Only industries with large excess capacities can assume major new roles without introducing short-term dislocations in skilled labor markets.

c. In Feasibility Appraisal: Production of Synthetic Fuel from Direct and Indirect Coal Liquefaction Processes, UOP/SDC examined four different technical processes for producing 1.0 MMBPD by 1990. This DOE-contracted study found that only one, liquefaction through the "methanol-gasoline" approach, would require more than 20 percent of the technical personnel, including engineers, employed by the firms capable of constructing liquefaction plants. This meant to UOP/SDC that the three other approaches, as well as an equally proportioned mix of all four techniques, would keep technical personnel requirements in construction firms below the "danger point" (p. 6-68B).

d. The synthetic fuels scenarios discussed above would, if implemented, all require massive increases in domestic coal production. Under a DOE contract, The MITRE Corporation prepared the 1980 report, Manpower for the Coal Mining Industry: An Assessment of Adequacy through the Year 2000. For this study MITRE developed a projection model which combined systems dynamics and econometric techniques. This allowed an analysis of personnel supply and demand based on interrelationships between technological change, labor productivity, production costs, wages, graduation rates, and other key variables. MITRE found that a shortage of mining engineers was unlikely by the mid-1980s. Only under a combination of extreme circumstances would shortages appear (Executive Summary, p. 4). MITRE, however, warned that there is currently a shortage of mining and mineral engineering faculty.

Based upon the above analysis of these reports, it is concluded that these studies are consistent with the earlier statement that "a synthetic fuels program of this scale would have only a very small effect upon science and engineering employment in 1990..." The supply of engineers should be generally adequate to produce 1.0 MMBPD by 1990, although there may be short-term dislocations in some engineering fields, particularly chemical engineering.[15/]

The Department of Energy is less optimistic on the subject of technical personnel available for the synthetic fuel industry, noting that the synthetic fuels program will place an early peak load on engineering capacity and will have to be carried out by engineers who are now active (Appendix D-4). Some of these engineers will have to be enticed away from other sectors of the economy which, in the opinion of DOE, could cause major dislocations in those sectors. DOE's Office of Energy Research has recently been given responsibility for energy-related personnel assessments, and plans to pursue a number of technology-specific projections during the next few years.

3. Doctoral Scientists and Engineers

Projections prepared by the National Science Foundation in 1978 (the methodology is described in a Technical Note in Appendix A) estimated that there would be more than enough Ph.D.'s through 1987 to fill available jobs at that level in four broadly defined fields: the mathematical, physical, life, and social sciences. These projections also indicated that there would be more than enough engineering Ph.D.'s in 1987.[16/] These NSF doctoral projections were extended to 1990 for the purposes of the present review. The 1990 projections indicate that an increasing percentage of science and engineering Ph.D.'s are likely to be employed in jobs that are not directly related to science and engineering. (According to a recent NSF study, many Ph.D.'s enter such employment because of their own preference.[17/]) Results of these Ph.D. projections are summarized in Table III.

The general findings of the NSF analysis for the four broad scientific fields are very similar to 1985 Ph.D. projections made by BLS in 1978. The two sets of projections differ, however, for engineering, where BLS foresees a Ph.D. shortage.[18/] Because the NSF projections did not account for the continued strong market for B.S. engineers, they may have overestimated future graduate engineering enrollments and, hence, future doctoral supply. If so, the market for Ph.D. engineers may remain tight through 1990.

It should be noted that computer professionals are included under the mathematical sciences in these projections, even though (as already discussed) many receive degrees from engineering departments. Available evidence on current graduate enrollments and industrial demand suggests that computer professionals at the Ph.D. level will be in short supply through 1990.[19/]

TABLE III

FULL-TIME SCIENCE AND ENGINEERING DOCTORAL LABOR FORCE BY FIELD
1979 ACTUAL AND 1990 PROJECTED
(in thousands)

	PHYSICAL SCIENCES	ENGINEERING	MATHEMATICAL SCIENCES	LIFE SCIENCES	SOCIAL SCIENCES	TOTAL
Labor Force						
1979	73	49	21	79	83	306
1990	103	80	30	113	125	450
Science/ Engineering Utilization						
1979	67	47	20	74	71	278
1990	93	63	23	93	99	370
Non-Science/ Engineering Utilization						
1979	7	3	1	5	12	28
1990	10	17	7	20	26	80
Non-Science/ Engineering Utilization as Percent of Labor Force						
1979	9	6	6	6	14	9
1990	10	21	23	18	21	18

Note: Detail may not add to totals because of rounding.

Source: National Science Foundation

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C. LIMITATIONS OF PROJECTIONS

Projections are useful for making general assessments of the future adequacy of the science and engineering labor force. For this purpose they are subject to limitations stemming from two chief sources. The first type of limitation is generic to all projections. It is caused by the impossibility of predicting all the events that may affect whatever is being projected, in this case the supply and utilization of scientists and engineers. The second type, which affects primarily the supply projections, results from an incomplete understanding of how students choose careers and how the science and engineering labor markets function.

In regard to the first type, uncertainties associated with national and world economic conditions can have major, unanticipated effects on science and engineering labor markets. For example, the demand for and price of particular goods and services might shift significantly, thereby shifting demands for all workers, including scientists and engineers.

The emergence of new technologies is another important factor which can have a potential influence on science and engineering labor markets. It may affect employment either by offering ways of more efficiently producing existing goods or services or through the introduction of new goods or services. To exploit these technical innovations, occupational specialities that do not now exist may emerge or openings in existing occupations may grow or decline unexpectedly. Thus technological change may cause market imbalances that cannot be foreseen when projections are made.

With regard to the second type of limitation, the NCES projections of baccalaureate and master's degree recipients do not account for how the market leads students into those fields with shortages and away from fields with poorer job opportunities. Therefore, the projections of new graduates, except at the doctoral level where adjustments are made by NSF for market effects, have a tendency to overstate both future shortages and surpluses. Also, current methods of projecting supply can make only crude adjustments for the widespread flow of students from the fields of their training to the other fields where they choose to work. These flows are often substantial when fields differ greatly in their relative balances between supply and demand. Additionally, forecasters are unable to predict how factors, such as public opinion about the role of science and technology in society, may affect the flows of new graduates.

Finally, the projections of engineering graduates presented in this report assume that engineering schools will be able to expand their enrollments sufficiently to meet projected class sizes. Some specialists question the validity of this assumption.[20/] Several reviewers also believe that the current excess demand for computer professionals and engineers is likely to continue and may become more severe.[21/]

In sum, such projections are adequate to the extent that assumptions are accurate and past trends continue; they cannot anticipate unforeseen structural breaks with past trends. However, we believe the general conclusions of this analysis stand in spite of these limitations and possibilities. They are based on such wide differences between projected graduates and job openings that only very large projection errors could invalidate them. In summary, the main points are in 1990: (a) the demand for computer professionals is likely to be greater than the supply of those trained in the field; (b) the labor market for a few categories of engineers should not be tight; and (c) the supply of scientists in all broadly defined fields should exceed requirements.

D. QUALITY CONSIDERATIONS

Assessments of the qualitative adequacy of the Nation's science and engineeering labor force necessarily require references to a set of norms. Examples of norms might include statements such as: (a) all college majors in science and engineering should be drawn from the top 15 percent of their high school class; (b) all college and university science and engineering faculty should have Ph.D. degrees; or (c) all personnel who enter science and engineering occupational specialties should have degrees in those specialties. In one sense, the quality of our science and engineering labor force can never be completely adequate because the Nation can always benefit from an improvement in the training and ability of science and engineering teachers, researchers, and other workers. Thus, any evaluation of the qualitative adequacy of the supply of scientists and engineers should be constrained by a recognition of the competing claims from other sectors of society for highly qualified people, the costs of training scientists and engineers, and the possible personal costs to those who regard themselves as underemployed, because they are not working in fields or specialities for which they were trained.

No indicators are available to measure or predict the future quality of American scientists and engineers. However, we do know a great deal about past U.S. scientific accomplishments. In the 35 years since the end of World War II, this country has established and maintained preeminence in many fields of knowledge. Evidence of U.S. scientific and technological leadership is found, to cite a few examples, in the record of the manned space-flight program, the continuing dramatic improvement in computer engineering, breakthroughs in our understanding of genetic processes, and new insights into the fundamental structure of matter. In recognition of pioneering work such as that cited above, American scientists and engineers have won 51 percent of the Nobel Prizes, excluding the prizes for peace and economics, awarded in the post-World War II period. Publication activity and citation analyses provide additional evidence of the past high level of productivity of U.S. scientists and engineers.

On the negative side, several indicators point to a relative decline in the technological advantage of U.S. industry compared with its foreign competitors. These indicators include relative changes in labor productivity and relative numbers of U.S. patents granted to U.S. and foreign applicants. No proven relationships exist between the quality of the science and engineering labor force and industrial productivity, though there are correlations, at least, between productivity and rates of research and development investment. However, it is at least plausible that the level of technical competence of all workers in an industry, <u>including</u> scientists and engineers, bears directly on the problem of improving industrial productivity. If so, then the qualifications of students who intend to enter science and engineering occupations are germane to the broad question of the adequacy of science and engineering education for long-term national needs.

Although it is clear that the current U.S. technical labor force contains a large share of the world's most productive scientists and engineers, some observers question whether the U.S. will be able to sustain this level of quality. Some of these observers maintain that the most able students are turning away from science and engineering to careers such as business, law, and medicine. Evidence suggests that such a sharply negative appraisal is not warranted.

The percentage of the science and engineering labor force holding doctoral degrees is one indirect measure of the ability of the U.S. to compete scientifically. A labor force better educated in science and engineering is better prepared to remain abreast of rapidly expanding scientific knowledge and to explore new areas of exceptional opportunity, such as recombinant DNA research. From 1973 to 1979 the number of active science and engineering doctorates expanded from 223,000 to 317,000, or 42 percent. The rising extent of advanced education among mathematical, physical and life scientists was marked by a doubling between 1960 and 1978 of the proportion of Ph.D.'s in the natural sciences labor force.

According to two indicators of the academic ability of young people planning science and engineering study, many able graduates will continue to join the science and engineering labor force during the 1980s. One of these indicators reflects the general scholastic capacity of future scientists and engineers as they prepare to enter graduate school.

Another indicator is the record over the past 14 years of the college study plans of those high school students selected as being the most capable in each year's graduating class.

The large majority of applicants to graduate school take the Graduate Record Examination (GRE) during their junior or senior year in college. Over the eight-year period ending in 1978, the test scores of prospective science and engineering graduate students on the quantitative components of the GRE remained high and unchanged both in absolute terms and relative to the average scores of graduate students in nonscience fields.[22/] In particular, candidates for graduate study in the physical sciences, mathematics, and engineering scored much higher on average than did those planning nonscience and engineering study. Undergraduates applying for admission to graduate life sciences programs scored well below the levels of candidates in the three fields above but still well above the average for nonscience and nonengineering applicants. On the verbal portion of the GRE, science and engineering applicants averaged about the same as did those applying for study in other fields.

Each year the National Merit Scholarship Corporation selects about 14,000 high school seniors as being the most gifted academically in the Nation. From these finalists, a fraction--about one-third in 1979--are chosen to receive Merit Scholarships. In each year from 1966 to 1979 at least 41 percent and as many as 49 percent of the scholarship winners indicated plans to major in engineering, the natural sciences, or mathematics, including computer science.[23/] These figures do not include those planning preparatory programs for the health professions or prospective social sciences majors. The larger group of finalists has had similar plans. In 1979 about 26 percent of both winners and finalists planned majors in the sciences and about 20 percent planned to study engineering. Although many high school seniors earn degrees in fields different from those which they indicate on entry into college, science and engineering continue to be attractive to many of the best students entering college each year.

These indicators apply only to students who are contemplating careers or at least majors in science and engineering fields. Broader assessments of the educational attainments of all high school students suggest that the science and mathematics competence of those who do not intend to pursue serious study in these fields has declined considerably since the early 1960s. These assessments are discussed in Section V-B.

In addition, indicators of the qualifications of students who enter college intending to pursue science or engineering majors or of those who enter graduate school in those fields provide no information about the adequacy of the education they receive in those institutions. A full assessment of the adequacy of professional science and engineering education would of necessity require reference to present and future expectations of prospective employers. However, even in the absence of such information, there are indications that the U.S. higher education system is under considerable strain and is not able to provide as high quality education in science and, more particularly, in engineering as many specialists believe it could.

REFERENCES -- SECTION II

1. National Academy of Engineering Task Force on Engineering Education. Issues in Engineering Education: A Framework for Analysis. Washington, D.C.: National Academy of Engineering, 1980, pp. 15-16.

   Paper submitted by the American Society for Engineering Education (Appendix D-2).

   This point was also emphasized by several evaluators of a draft of this review, including Donald Glower (The Ohio State University), Donald Marlowe (American Society for Engineering Education), and F. Karl Willenbrock (Southern Methodist University).

2. Current spot shortages in industry in several engineering fields and in scientific subdisciplines were reported by participants in National Research Council Seminars V-A and B (Appendix E). Their existence was also noted by several evaluators of an early draft of this review, including Lewis Branscomb (International Business Machines Co.), William Hubbard (The Upjohn Co.), and J.E. Stevenot (Proctor and Gamble Co.).

3. National Council of Teachers of Mathematics, Press Release, October 19, 1978, Reston, VA.; B.G. Aldridge, "Announcement of Results of the National Science Teachers Association Survey (1980)." Washington, D.C.: NSTA.

4. NSF Division of Science Resources Study (unpublished report). Employment and Training Report of the President, 1979.

5. Engineers Joint Council, Engineering Manpower Commission. Placement of Engineering and Technology Graduates, 1979. New York, October 1979.

6. A June 17, 1980 news release from the College Placement Council (Bethlehem, PA) notes that the number of job offers to new engineering baccalaureates has increased by 21 percent since June 1979.

7. National Research Council Seminar IV-B (Appendix E).

8. op. cit., Note 2.

9. Based on data in recent annual issues of Summary Report, Doctoral Recipients from U.S. Universities, published by the National Research Council.

10. College Placement Council. Salary Survey-Final Report. Issued annually from Bethlehem, PA.

11. College Placement Council, Bethlehem, PA. Unpublished survey.

12. op. cit., Note 1.

13. Comment on early draft of this review by James G. Ling, Department of Energy.

14. Office of Higher Education, U.S. Department of Agriculture, "Report of Manpower Assessment Project," 1980 (unpublished).

15. The existence of shortages of chemical engineers was cited by Lewis Branscomb (International Business Machines Co.) and J.E. Stevenot (Proctor and Gamble Co.) in critiques of an early draft of this review.

16. National Science Foundation. Projections of Science and Engineering Doctorate Supply and Utilization: 1982 and 1987. NSF Report #79-303.

17. National Science Board. Science Indicators, 1978. Washington, D.C.: U.S. Government Printing Office, 1979, p. 119 (Table 5-2).

18. Douglas Braddock. "The Oversupply of Ph.D.'s to Continue Through 1985." Monthly Labor Review, October 1978, pp. 48-50.

19. According to the National Center for Education Statistics, Ph.D.'s in computer science grew from 107 in 1970 to 196 in 1978. Such growth in new graduates is not expected to be sufficient to meet the anticipated rapid expansion in industrial and academic demand for doctorates in this field. See also Jerome A. Feldman and William R. Sutherland. "Rejuvenating Experimental Computer Science." Communications of the ACM: v. 22, #9. Sept. 1979, pp. 497-502.

20. op. cit., Note 1.

21. Several persons expressed this belief in assessments of an early draft of this review. They include Kenneth Baker (Harvey Mudd College), Lewis Branscomb (International Business Machines Co.), Donald Glower (The Ohio State University), John Whinnery (University of California, Berkeley), and F. Karl Willenbrock (Southern Methodist University).

22. op. cit., Note 17, pp. 125-129.

23. National Merit Scholarship Corporation, Annual Report (issued yearly).

SECTION III. SCIENCE AND ENGINEERING EDUCATION AT UNIVERSITIES AND FOUR-YEAR COLLEGES

A. INTRODUCTION

The Nation's higher educational system has been the foundation of the extraordinary growth and superb quality of the science and technology that gave the United States preeminence in these fields during World War II and the succeeding quarter century. Since the early 1970s, however, American colleges and universities--including their science and engineering faculties--have had to reassess their functions and role in American society because of the effects of demographic change, increasing financial pressures, and new social and economic imperatives.

In particular:

- Except in engineering and the computer professions, undergraduate science enrollments, which expanded dramatically in the 1950s and 1960s, have generally leveled off or declined.[1/] Since the size of the 18- to 24-year-old age group will continue to decrease over the next twenty years, there is no doubt that the competition for undergraduates among American colleges and universities will continue.[2/]

- Student populations have become more heterogenous, and their preparation, interests, and needs more diversified, as larger proportions of minorities, women, and adults attend college (Appendix C).

o Costs are outstripping income for virtually all colleges and universities, because of inflation, a leveling off of income from tuitions and fees and, for private institutions, decreasing returns on endowment investments.[3/] Research universities began to experience additional financial pressures due to decreased Federal research support in the early 1970s.[4/] While the level of research support has increased since 1975, the effects of the earlier declines are still evident.[5/]

Rising costs coupled with high starting salaries for new engineers and computer professionals at all degree levels have led to urgent and immediate problems for schools and departments in these fields:

o The number of doctoral degrees granted continues to decline;[6/]

o Engineering and computer professional faculties are understaffed, with little prospect for early improvement;[7/]

o Facilities needed to conduct research have become obsolete, and apparatus to instruct students in state-of-the-art industrial practice is generally unavailable.[8/]

The demographic and financial factors noted above have also led to stresses in other parts of the higher education system which, if not relieved, could result in future dislocations:

o Decreasing growth rates of support for scientific research and declining enrollments have led to a static hiring situation in university science departments. With so few openings for the new generation of scientists, there is a distinct possibility that university science faculties will lack the flexibility to pursue innovative research and instruction;[9/]

o Obsolescence of research and teaching equipment, while not as severe as in engineering, is also a growing problem for science departments at both the graduate and undergraduate levels;[10/]

o Because of generally tight budgets, science courses and curricula in many four-year colleges are falling behind the times, and faculty at these institutions have decreasing opportunities to keep up with their fields.[11/]

The remainder of this section analyzes information from pertinent literature and from contributors to this review under the following headings: (B) The Education of Engineers and Computer Professionals, (C) Science Education at the Graduate Level; and (D) Science Education at the Undergraduate Level. Section IV considers: (A Science and Education at Community Colleges; (B) Continuing Education in Science, Technology and Engineering; and (C) Informal Opportunities for Science and Technology Education.

B. THE EDUCATION OF ENGINEERS AND COMPUTER PROFESSIONALS

At present, the market for engineers in most fields and at all degree levels remains tight (Section II). Undergraduate enrollments in engineering have been increasing since 1973, and the number of bachelor's degrees awarded has increased since 1976.[12/] Part of this increase is due to the entry of women who, in the fall of 1979, composed about 15 percent of freshman enrollments in engineering.[13/] The number of master's degrees granted in engineering has leveled off, and Ph.D. production has declined by 30 percent since 1972.[14/] These trends are due, in part, to the impressive starting salaries that bachelor's degree engineers can command, coupled with the decreased availability of fellowships and traineeships for graduate study.[15/] The numbers of candidates for both the master's and the Ph.D. degree exhibited slight increases between 1978 and 1979.[16/] However, it is still too early to determine whether these increases mark a significant reversal in the earlier trends.

About one-third of all Ph.D. engineering candidates are foreign nationals, two-thirds of whom are in the U.S. on student visas.[17/] Although many of those in the latter category may remain in this country, the total number of new Ph.D.'s who enter the U.S. labor force each year will be less than the number who receive their degrees.

Computer professional fields represent the single broad area in which there are clear shortages of personnel at all degree levels at the present time and where those shortages are projected to continue through 1990 (Section II-A and B). People who enter the computer science professions receive their degrees from several types of college and university departments, most of which also offer instruction in other, related specialities. These departments include mathematics, electrical engineering, and business administration, in addition to those designated as computer science departments.[18/] Trends for computer professionals have been similar to those for engineering: namely, rapidly rising undergraduate enrollments and decreasing Ph.D. production.

Unlike the traditional engineering fields, however, the computer professions are relatively young disciplines that did not even constitute a separate, coherent field twenty years ago. Consequently, the inflow of people trained in other specialties continues to be much higher than for any other fields (Section II-A). Indeed, most senior faculty in departments specifically designated as computer science departments received their Ph.D.'s in some other specialty.[19/]

Declining Ph.D. production and the availability of more attractive employment opportunities in industry for persons with doctorates in engineering and the computer professions have led to a shortage of both junior and senior faculty in these fields.[20/] A survey of representative engineering schools indicates that there are as many as 2,000 unfilled positions in engineering. Likewise, there are approximately 200 vacancies in departments that specialize in the computer professions.[21/] These vacancies are straining the capacity of these schools and departments. The size of many undergraduate classes has increased beyond what some experts regard as desirable for effective instruction.[22/] Moreover, the decreasing availability of graduate students to serve as teaching assistants has further added to the burden on senior faculty, leaving them with less time for individual student contact and research.[23/]

A good deal of the laboratory equipment and the physical facilities being used for both research and teaching purposes in university engineering and computer profession departments was acquired during the 1960s. Their obsolescence has been cited as a severe problem for education in these fields.[24/] Lack of access to state-of-the-art research facilities for university faculty and graduate students decreases the attractiveness of academic careers and contributes to the engineering and computer profession faculty shortage problem. The obsolescence of instructional equipment implies that part of the education that undergraduate engineers and computer professionals receive is itself obsolete vis-a-vis current industrial practice.

Engineering and the computer professions have always been strongly influenced by technical innovation and commercial opportunity. Throughout the 1950s and 1960s and into the early 1970s, these stimulated growth in university research and graduate education. During those years, research in these fields carried out in university laboratories led to results that catalyzed a number of significant industrial innovations. Industries for their part greatly expanded their research efforts and their investments in research facilities at a time when funds for these increasingly sophisticated facilities were becoming difficult for university laboratories to acquire and maintain.[25/] According to one specialist, underinvestments in engineering facilities, equipment, and instrumentation during the 1970s resulted in an accumulated shortfall of about $750 million in U.S. engineering schools at the beginning of the 1980s.[26/]

Thus, the noncompetitiveness of academic salaries, while an obvious contributing factor to the engineering and computer professional faculty problem, may not be of overriding importance. University faculty have traditionally been willing to forego higher salaries outside of academia in exchange for opportunities to conduct research and work with good graduate students in a university setting. However, many observers believe that difficulties in obtaining research support, lack of stability in Federal research support and, most importantly, the existence of greatly superior research facilities in industry have all contributed to the decreasing attractiveness of academic careers.[27/]

The obsolescence of instructional equipment and facilities in engineering schools has led to a somewhat different problem. During the 1970s, computer-assisted methods in manufacturing have begun to provide important gains in productivity for some large U.S. industrial companies, and are good examples of the dramatic changes that are occurring in engineering practice. However, the apparatus required to teach these methods to students is generally unavailable to engineering schools. In fact, a good deal of the instruction now being offered may be obsolete simply because it makes use of obsolete equipment. A similar situation is evident in many computer profession departments. While this situation may not pose significant problems for the large employers of engineers that can afford on-the-job training for newly-hired personnel, specialists argue that it could have appreciable affects on smaller companies and industries which traditionally have counted on new graduates to keep them abreast of the latest developments.[28/]

The faculty shortage and equipment obsolescence problems have led some specialists to conclude that the capacity of engineering schools and computer profession departments to accept and provide an adequate education to all qualified applicants may be reached during the present decade. Additionally, the rigidity implied by the strained capacity of these schools and departments limits their ability to respond to changing demands of the engineering labor market. It is probably the case that long-term solutions to the faculty shortage, equipment obsolescence, and rigidity problems must derive from the establishment of close working relationships between universities and industry. For example, industry could make its unique research facilities available to university faculty, offer sabbatical year arrangements whereby university faculty would engage in industrial research while industrial engineers and computer specialists taught and conducted research in university departments, and developed work study programs for students at all levels--undergraduate, graduate, and post-doctoral.[29/] However, there is some evidence that current tax, patent, anti-trust, and copyright laws and regulations are creating barriers to more effective university-industry cooperation.[30/]

Given the long training cycle that characterizes the formal educational process, even a much more flexible system than presently exists could never hope to respond without an appreciable time lag to rapidly changing demands for specific types of engineering and scientific training. Thus, while market forces will almost certainly relieve spot shortages that currently exist in specific engineering subfields, spot shortages in other subfields that cannot be identified at present are almost certain to occur in the future even if, as anticipated (Section II-B), the aggregate supply of engineers is sufficient. This supposition argues in favor of closer university-industry cooperation in anticipating and preparing for future demands. It also argues for engineering curricula that provides a broad conceptual foundation in addition to training in specific techniques and thus provides new graduates with the capability to retrain themselves in fields that may be somewhat different from those of their original major.

In the latter regard, it is worth noting that the dramatic changes that have taken place in engineering practice and rapid changes in computer technology and its utilization, coupled with the strained capacities of engineering schools that have resulted from faculty shortages and obsolescent facilities and equipment, have intensified a long-standing philosophical debate among engineering educators and industrial employers about the appropriate content of the engineering curriculum. This debate focuses on the optimum balance to be achieved between science-based training and training in engineering design, development, and production.[31/]

Participants on both sides of this debate recognize that since science and technology are closely related activities, science and engineering education must continue to share many commonalities. However, they also suggest that there are important distinctions between science and engineering education and that to blur those distinctions by lumping together problems in the two areas works to the detriment of each.

In particular, a bachelor's degree in engineering, unlike a bachelor's degree in one of the sciences, is a professional degree that can lead directly to licensing and certification. Thus, it is argued, engineering schools should in some senses be regarded as equivalent to schools of medicine or law rather than undergraduate schools of arts and sciences. Several indicators give additional weight to the distinction between engineering and science education: pressures toward a five-year bachelor's degree course in engineering, the higher costs of training undergraduate engineers relative to most undergraduate scientists, the desirability of industrial internships for undergraduate and graduate students, the attractive salaries currently available to engineering faculty, and the increasing numbers of engineers who take advantage of continuing education opportunities offered by industry or who seek advanced degrees in mid-career.

The debate about whether and to what extent engineering schools should adopt a so-called medical school model and divorce themselves from their traditional association with faculties of arts and sciences is far from settled, and probably will not be resolved in a manner that satisfies all participants in the debate about the content of the engineering school curriculum. Specialists point out that engineering schools differ in the mix of science-based and practice-based curricula they offer, in recognition of the fact that both types of education are necessary, though individual students may choose to concentrate more heavily on one type of training than the other. Indeed, the desirability to preserve a broad range of options in engineering education has been cited as a fundamental reason for the conviction, among educators, that the multiple stresses on the system need to be relieved.[32/]

C. SCIENCE EDUCATION AT THE GRADUATE LEVEL

As discussed in detail in Section II, current indicators point to excesses over demand in the number of degrees granted in all broad fields of science (i.e., mathematical, physical, life, and social sciences), and projections indicate that this situation will persist in 1990. However, spot shortages are presently reported in a number of scientific subspecialties, particularly at the Ph.D. level.

Unlike the case of engineering and the computer professions, a bachelor's and to some extent a master's degree in science or mathematics is usually not regarded as a professional degree. That is, students may major in one of the sciences for a number of reasons besides aspiring to research careers in their major fields. The life sciences, for example, are considered to be desirable major fields for pre-medical students.

In contrast, students who pursue Ph.D. degrees in science or mathematics have traditionally aspired to research positions in university, industry or government laboratories, though many also obtain employment in nonscientific professions (Section II, Table III). It is therefore convenient to discuss the current status of higher education in science at the undergraduate and post-graduate levels separately.

University science departments face a particular set of problems because of the intimate connection, at the Ph.D. level, between instruction and research. The rapid university expansion in the 1950s and 1960s was fueled in part by increasing Federal research grants to universities.

These expanding research opportunities, coupled with rising undergraduate and graduate enrollments, led to rapid growth in the size of many university science faculties, the establishment of new Ph.D. programs in several institutions, and promotions to tenure rank for many young scholars, many of whom are not due to retire until the 1990s.[33/] During these years university graduate programs in science and mathematics were sharply focused on preparing students for research and teaching positions in what appeared to some to be an almost endlessly expanding academic market. But in the early 1970s, the sizes of science and mathematics faculties began to stabilize and, in some cases, to decrease as Federal research support declined and the growth rate of undergraduate enrollments slowed down.[34/] As a result, junior faculty positions have become relatively scarce, particularly in physics and mathematics and most of the social sciences.[35/]

Since 1975, the number of Ph.D.'s awarded in the physical and mathematical sciences has decreased sharply in partial response to the continuing weak demand in the academic sector, though degrees in the life and social sciences have remained approximately constant.[36/] As previously noted, spot shortages in industry are currently reported in several subfields of physics, chemistry, and biology. Future shortages may also appear in subareas where opportunities for rapid advances occur because of unanticipated progress in those areas. Some observers are concerned that the total number of new Ph.D.'s (particularly in the physical sciences) may not be sufficient to respond to these opportunities.[37/] However, in view of the findings reported in Section II-B regarding the sufficiency of Ph.D.'s in all broad fields of science, the capability of university science departments to equip Ph.D. candidates to take advantage of such new opportunities in industry by changing the focus of their specialty may be a more reasonable ground for concern.[38/] Several observers also believe that the lack of opportunity for academic employment might deter the most able students from pursuing graduate study in the sciences. Graduate Record Examination scores indicate, however, that on the average the qualifications of college seniors seeking admission to graduate science departments have remained approximately constant for a decade (Section II-D).

Concern has been expressed that with decreasing Ph.D. enrollments in the mathematical, physical, and life sciences, there may not be enough qualified candidates to fill vacancies in colleges and universities created by the large numbers of faculty retirements that are anticipated in the mid-1990s.[39/] The rigidity implied by heavily tenured faculties rather than a particular age distribution per se is a serious problem. Such rigidities may limit the ability of colleges and universities to alter the allocation of scarce resources among teaching faculties as may be demanded by changing market conditions. Finally, the fact that many science and mathematics departments cannot bring in "new blood" could hamper their ability to provide innovative instruction and research opportunities to their students.

The direct effects of rising costs and changing demographic and market trends on the overall, short-term capacity of the academic system to educate sufficient numbers of well-trained scientists are probably less important than their probable long-range effects on the research capabilities of university science departments. The quality of graduate education in science is closely related to the research opportunities available to Ph.D. students. Therefore, any changes in university research capabilities will of necessity have a direct effect on education at that level, particularly on the capability of graduate departments to orient their programs toward a predominantly industrial as opposed to an academic market.[40/]

The high cost of maintaining existing laboratory apparatus and of replacing obsolete equipment has been cited as a serious problem in this regard for university science departments as it is for engineering schools. Even the Nation's major research universities have not kept pace in meeting instrumentation needs. A good deal of research in the natural sciences requires capital investment in buildings and large research installations. Laboratory equipment and special instrumentation are also capital costs, but their useful life is typically shorter than that of buildings.

The major role that university users play in the development of scientific instrumentation has been demonstrated in a recent study of 111 scientific instrument innovations which culminated in the successful commercialization of those instruments. The instruments selected for study were of special importance to chemical and biological research. Of the 44 improvements in the basic instruments which were incorporated into a commercial product, users rather than instrument manufacturers dominated the innovation process in 81 percent of the cases. It is of particular significance that, of the users who contributed to the innovations, 72 percent were employed by universities or affiliated research institutes rather than by private manufacturing firms or other nonuniversity organizations.[41/]

Equipment-intensive research areas such as physics, engineering, chemistry, and the life sciences have experienced a decade in which the development, purchase, and maintenance costs of instrumentation have escalated rapidly, while the state-of-the-art apparatus, needed to conduct research at the cutting edge of science, has become increasingly sophisticated--and expensive.[42/] The Science Council of Canada estimates that equipment costs due to increasing sophistication rose at an average rate of 4 percent above inflation during the 1970s.[43/] However, Federal funds for research equipment declined during this same period. The fraction of NIH research project support allocated to permanent equipment declined from 11.7 percent in 1966 to 5.7 percent in 1974; NSF showed a decline in the proportion of grant funds for permanent equipment from 11.2 percent in 1966 to an average of 7.1 percent for the years 1969 to 1976.[44/]

Industrial laboratories, in contrast, have continued to equip themselves with needed scientific apparatus. A recent comparison of university instrumentation inventories with those of two leading commercial laboratories reveals that the median age of university equipment is twice that of commercial laboratory instrumentation.[45/] This survey indicated that in the leading industrial laboratories, the pace of research is limited by the imagination and capacity of the engineers and scientists rather than by the apparatus available to them. One observer summarized this disparity with the remark that "The ivory towers are now in industry."[46/]

Greater flexibility in Federal research grant and contract administration that would encourage pooling of equipment funds and sharing apparatus between university departments has been suggested as a partial remedy to the equipment obsolescence problem. Other suggested measures include further development of regional instrumentation centers and enhanced university-industry cooperation, as discussed in Section III-A. While these measures could increase the accessibility of up-to-date apparatus to Ph.D. students, most of them would tend toward centralization of research facilities with the result that many advanced graduate students and faculty would spend less time in residence on their own campuses. Several disciplines and subdisciplines, such as oceanography and high-energy physics, have long since adapted to the necessity of using centralized research facilities. Thus, national laboratories (or Federally Funded Research and Development Centers) have the dual function of carrying out their own intermural research programs in these fields and maintaining sophisticated research facilities for university-based user groups. One result has been that personnel at such laboratories often assume the role of virtual thesis advisors to advanced graduate students. Such arrangements have permitted substantial research progress, and some specialists believe that they will have to be extended to other fields of science as the cost of maintaining adequate laboratory facilities exceeds the capacity of individual universities or university consortia. However, the effects on the teaching capacities of university science departments of a more wide-ranging centralization have yet to be fully assessed.[47/]

D. SCIENCE EDUCATION AT THE UNDERGRADUATE LEVEL

During the period of rapid expansion of university science departments, the primary thrust of undergraduate major programs both in universities and four-year colleges was to prepare students for graduate or professional study. Since Graduate Record Examination scores of seniors who intend to pursue graduate study in science remain constant, presumably undergraduate departments are fulfilling that traditional role adequately (Section II-D).

Even during the period of expansion, however, more students were awarded bachelor's degrees in science and mathematics than sought admission to graduate or professional schools. Some of these students entered science-related occupations; others, by their own preference, sought other types of employment. That situation has not changed, despite decreasing undergraduate enrollments.[48/]

Some new bachelor's degree recipients in the physical sciences who enter the labor market directly after graduation find industrial positions that could also be filled by engineering graduates. The demand for such graduates can be high during periods when the market for new bachelor's level engineers is tight, and thus they provide a degree of flexibility to the industrial science and engineering labor market.[49]

Since many undergraduate science majors neither pursue graduate work in science nor enter science-related occupations, it can be presumed that they perceive advantages in having a strong background in science and mathematics even though they have no intention of pursuing science-related careers. However, such students may hope to make some use of their special education.

If, as many believe, it is advantageous to the Nation to populate nonscientific professions such as business, law, and journalism with scientifically qualified people then the requirements of those who have the interest and capacity to pursue rigorous studies in science and mathematics, but who do not intend to pursue graduate work, ought to be addressed. There is little evidence to suggest that this is happening, either at four-year colleges or universities. Indeed, undergraduate science education has been criticized as being too theoretical and esoteric for most students, and still oriented toward those who are intent on graduate study. Neither the needs of those who intend to enter the labor force directly after graduation nor those who intend to pursue nonscientific careers appear to have been adequately addressed.[50/]

Historically, a substantial proportion of students entering Ph.D. programs in the sciences have come from four-year liberal arts colleges. Like the universities, these institutions are experiencing stresses due to changing demographic patterns and continuing high inflation rates. Their science and mathematics departments have also been affected by declining Federal support for curriculum and faculty development. As a result, faculty members in science departments at many four-year colleges feel that they are falling behind in their ability to provide quality, up-to-date education to their students.[51/] Yet these faculty are usually more heavily involved in teaching than their colleagues in university departments who also pursue research activities. Therefore, provided adequate support were forthcoming, four-year college faculty could be in a good position to develop new types of undergraduate science and mathematics curricula.

In addition to undergraduates who major in science or mathematics without planning to pursue graduate study in those fields, there are others who do not major in science or mathematics but who take courses in these fields either as a part of their general education or because either they or their faculty advisers regard some preparation in science and mathematics as desirable or necessary in their intended occupations.

There is no consensus about the best content of science and mathematics courses for nonmajors. Many departments offer special courses for them which are usually less rigorous and more descriptive than their major courses. However, such courses may not satisfy the requirements of students who need a reasonable familiarity with science for occupational reasons. In addition there is anecdotal evidence that some students avoid more rigorous courses because of poor preparation in mathematics or because they have the reputation for being too difficult.

Finally, there are numerous college students who take no science or mathematics at all and, therefore, many who have no exposure to formal science beyond 10th grade biology or to mathematics beyond 10th grade geometry. It does not follow, however, that these students are not interested in the relationships of science, technology, and society. On the contrary, a recent survey conducted by the American Association for the Advancement of Science identified over 500 American colleges and universities that offer at least one course in this area or in fields such as the history or sociology of science. Almost 120 multi-course programs in the science, technology, and society area were identified among these 500 institutions. Many of these programs are interdisciplinary undertakings between science, or engineering, and social science and/or humanities departments, and student enrollments in most of them appear to be reasonably good.[52/]

Interdisciplinary courses in science, technology, and society address concerns likely to be of importance to students regardless of their future occupations. Therefore, their apparent relative popularity is a positive development. However, few such courses lead to familiarity or competence with the concepts and processes of science and technology themselves. In some cases, descriptive courses already offered by many science departments may be adequate for these purposes, but many contributors to this review believe that a different approach is in order, and that the advent of modern electronics--calculators, computers, and video systems, for example--may provide the requisite means.[53/] Since electronics is transforming the ways in which business and industry are conducted, it would be useful to incorporate it into the educational system. Computers could be used to stimulate nonscientists toward a greater interest in science and alleviate problems many students face because of inadequate preparation in mathematics.

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8. ibid.

9. National Research Council Seminar V-A (Appendix E). The NRC report, Research Excellence Through the Year 2000, discusses the academic supply and demand picture (Appendix F).

10. The equipment problem has been widely discussed. In Note 5 above, Smith and Karlesky treat it in some detail and the paper submitted by the Association of American Universities also includes the problem among the issues they raise.

11. This point was emphasized by several contributors to this review, including the participants in NRC Seminar III-B (Appendix E), B.F. Howell, Jr., The Pennsylvania State University (Appendix D-2), and D. Kenneth Baker, Harvey Mudd College, in an evaluation of a draft of this review.

12. Engineering and Technology Enrollments, Fall 1979, Part I, p. 10. Engineering Manpower Commission of the American Association of Engineering Societies.

13. ibid, pp. 19-26.

14. op. cit., Note 6.

15. Paper submitted by the American Society for Engineering Education (Appendix D-2).

16. op. cit., Note 12.

17. Based on data in recent annual issues of Summary Report, Doctoral Recipients from U.S. Universities published by the National Research Council.

18. At four-year colleges, computer professionals often receive their degrees from mathematics departments. The ASEE (Note 13) maintains that engineering schools have assumed the burden of educating computer professionals at the graduate level, noting that the 1980 Engineering Graduate Study Directory shows 105 entries for computer science, 119 for civil engineering, and 139 for electrical engineering.

19. Lee Grozdin. "The Field Mobility of Doctoral Scientists and Engineers." (NRC Paper, Appendix D-1).

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21. Jerome A. Feldman and William R. Sutherland, "Rejuvenating Experimental Computer Science." Communications of the ACM, Sept. 1979, v. 22, #9, pp. 497-502.

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34. op. cit., Note 1.

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41. American Association of Universities. op. cit., Note 25, p. 3.

42. op. cit., Notes 10 and 25.

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46. op. cit., Note 25, p. 20.

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48. op. cit., Note 4, p. 119, Table 5-2.

49. Business-Higher Education Forum, "Engineering Manpower Forum: Must It Always Be Feast or Famine?" Washington, DC. April 1980 (unpublished). This paper breaks down the supply of new bachelor's degree level entrants into the following four categories, with approximate percentages in recent years indicated in parentheses: engineering graduates (70 percent); immigrant engineers (5 percent); other recent graduates (8 percent); and transfers in (17 percent). The recent graduate category consists primarily of bachelor's degree recipients in mathematics and physical science; the transfers in category is composed of technicians and underutilized scientists upgraded on the job.

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SECTION IV: ADDITIONAL COMPONENTS OF POST-SECONDARY SCHOOL SCIENCE AND ENGINEERING EDUCATION

Most contributors to this review agree about the need to devote more attention to education in science and technology for those who are not--and will not become--professional scientists and engineers, and to opportunities for scientists, engineers, technicians, and teachers to upgrade and maintain their knowledge and skills. This section reviews the roles played at present by: (A) community colleges; (B) continuing education centers; and (C) the mass media, in pursuing these and other tasks associated with science and engineering education.

A. SCIENCE AND TECHNOLOGY EDUCATION AT COMMUNITY COLLEGES

Public community colleges have constituted the fastest growing segment of higher education over the last two decades. Between 1960 and 1977, 71 percent of the institutions established were two-year colleges.[1/] Enrollment in these colleges grew by 169 percent from 1967 to 1977, compared to an enrollment growth of 65 percent for all institutions over that time period.[2/]

Prior to the growth era, two-year colleges functioned mainly to provide the initial portions of a college transfer program and many still consider this function significant. Many community colleges still serve as the beginning of four-year degrees for many students. They are particularly important as a source of technicians who later become engineers either by going on directly to an engineering school or as a result of on-the-job training. About the same proportion of Blacks attended two-year colleges as attended four-year colleges and universities. Hispanics were more likely to be enrolled in two-year colleges than in other institutions.[3/]

But the growth in numbers of two-year colleges was accompanied by an expansion of their scope to include a host of vocational programs. This included two-year colleges assuming functions formerly handled outside the formal educational system such as training of police, fire-fighting personnel, and technicians.

Two-year colleges play an important role in training technicians. Formerly, technicians were typically trained on the job and to this day a substantial amount of on-the-job upgrading of technical personnel occurs. However, over the past decade the number of students earning associate degrees (requiring at least two years, but less than four years of work beyond high school) has risen by almost two-thirds, from 252,610 in 1970-71 to 412,246 in 1977-78. But associate degrees in science and engineering-related fields have risen at an even faster rate, more than doubling during that period. Among these fields, health services and paramedical degree-holders almost tripled; in 1970-71, 21,269 such degrees were awarded, increasing to 62,030 in 1977-78. At the same time, degrees in natural science technologies more than doubled, degrees in mechanical and engineering technology grew by two-thirds, while those in data processing increased by 25 percent.[4/]

Science and engineering education in two-year colleges shares a number of problems with the higher education system regarding faculty, curricula, and equipment (Section IV-C). Public two-year colleges also face some unique problems: low retention rates; increased competition from comprehensive colleges and universities searching for students; decreased funding from the local sources on which the colleges heavily rely (financing of two-year colleges comes heavily from local tax sources); increased competition from electronic means of delivering education; and poor preparation in mathematics on the part of students, which absorbs considerable resources for remedial teaching.[5/]

Teachers of science, mathematics, and technical subjects in community colleges have problems different from those of their colleagues in four-year institutions. Their outstanding problem, at least in mathematics, is teaching unmotivated students. Little systematic information is available either about the quality of their course offerings in science and technology, or about the needs of industry for their graduates. Since attainment of important long-term needs will depend heavily on the technical competence of the skilled U.S. work force, it would be desirable to gather information to permit an assessment of the most appropriate ways to exploit the unique potential of community colleges to serve the needs of local markets. It would also be useful to provide opportunities for sustained, substantive interactions between teachers of science and mathematics at two-year colleges and their colleagues in universities and industry to improve coordination among the various components of the post-secondary school science and engineering education system.[6/]

B. CONTINUING EDUCATION IN SCIENCE, TECHNOLOGY, AND ENGINEERING

Change is intrinsic to science and technology, and the structure of science and technology fields often alters as their content develops. New fields spin off from old, and the boundaries between separate fields may coalesce to form new interdisciplinary fields with lives of their own. Nuclear engineering, computer science, and environmental science provide three recent examples of such structural developments. Such changes depend on the occupational mobility of scientists and engineers--their ability to sense new opportunities and move into new specialty areas. Traditionally, preparation for Ph.D. degrees in science and engineering has provided a foundation that has facilitated later field mobility. The organization of the academic scientific community has encouraged mobility by publishing professional journals and organizing meetings where research scientists and engineers can interact with their colleagues. Lee Grodzins estimates that 25 percent of all doctoral scientists make a major change away from the broad field of their Ph.D. during their career, and 30 to 40 percent of the rest change their specialty.[7/]

Field mobility is also essential in industry, particularly for engineers, to permit the exploitation of new opportunities and to help relieve personnel shortages in particular subfields. Organized continuing education programs are frequently used to facilitate mobility. Continuing education can serve other purposes as well: upgrading the skills of technicians to the level of a bachelor's degree in engineering, allowing mid-career engineers to earn Ph.D. degrees, or broadening the skills of scientists and engineers so that they qualify for jobs in related fields or in other nonscience and engineering jobs. It can take many forms: informal on-the-job activities, short courses and institutes, correspondence courses, courses offered by television, videotape or newspaper, and formal courses on college campuses.[8/]

Although data are fragmentary, there are indications that significant numbers of scientists and engineers take advantage of opportunities for continuing education. During the academic year 1975-76, 56 universities offered over 3,500 credit courses for scientists and engineers--47 percent of them on campus and 53 percent off campus, and over 30,000 scientists and engineers were enrolled in them. During the same year, almost 5,000 separate noncredit continuing education courses were offered to scientists and engineers--72 percent by universities and 28 percent by professional science and engineering societies. Almost 190,000 scientists were enrolled in them.[9/] No firm data about the number of mid-career professional engineers who are pursuing Ph.D. degrees are available, but anecdotal information suggests that the number may be increasing.[10/]

Given anticipated future changes in science and particularly technology, continuing education--both on the job and on the campus--is likely to become an even more important feature of the education of scientists and engineers. However, according to a report prepared for the Industrial Research Institute, industry has assumed a disproportionate share of the responsibility for the continuing education of scientists and, more particularly, technicians and engineers.[11/] Moreover, many universities experience difficulty in developing effective continuing education programs for industrially employed scientists and engineers due to academic reward structures that favor research, publication, and the teaching of traditional degree candidates over continuing education. Finally, continuing education at universities is expected to be completely self-supporting through tuition receipts.[12/]

Some industrial firms, particularly those with large research and development capabilities, have established wide-ranging continuing education programs for their personnel. However, most firms must depend on external sources for continuing education, and often these do not exist or are inaccessible. Potentially available sources in industry become increasingly proprietary and unavailable to other firms as the knowledge base for providing continuing education moves from the university to industry. Since education is not the primary area of competence for industrial firms, they would prefer not to compete with universities in offering it. Yet they find themselves increasingly forced to do so.[13/]

At present, continuing education is a fractionated, uncoordinated set of operations in which academia, industry, professional societies, and individual entrepreneurs pursue their own individual paths in response to what they perceive as their individual needs. There has been virtually no Federal support for continuing education, in part because the costs of industrial programs have been regarded as business expenses. However, since continuing education can provide a rapid and focused means for relieving spot personnel shortages in specific subfields and for improving productivity by renewing the skills of mid-career scientists and engineers in industry, it could provide a relatively cost-effective means for the Federal Government to intervene in the science and engineering labor market when clear national needs require such intervention.

Continuing education is also important to help science and mathematics teachers in secondary schools, community colleges, and four-year colleges remain current about new developments in their fields. Indeed, many school systems either require or provide financial incentives to public school teachers to take formal post-graduate courses for credit. During the period of rapid expansion for science and engineering education in the 1950s and 1960s, summer institutes and in-service academic year institutes offered a special type of continuing education opportunity for science and mathematics teachers. These institutes also offered secondary school teachers the chance for sustained interaction with university scientists and engineers.

At present, the Federal Government no longer supports such institutes, although it does provide modest support to other types of faculty-development programs. In view of the declining condition of secondary school science and mathematics teaching (Section VI-D) and the isolation of science and mathematics teachers in community and many four-year colleges, more substantial faculty development efforts--including some types of institutes--might be considered as appropriate policy options.

C. INFORMAL OPPORTUNITIES FOR SCIENCE AND TECHNOLOGY EDUCATION

In addition to organized continuing educational offerings that focus on upgrading or broadening particular occupational and professional skills, there are other types of opportunities for the general adult population in the United States to acquire information about science and technology. These informal educational opportunities are provided through several different types of media: newspapers, magazines, radio and television (particularly public radio and television), and science and technology museums and related institutions such as planetaria, zoos, nature centers, and parks.[14/]

The desire of much of the nonscience and engineering public (estimated as being as large as 18 percent[15/]) to maintain at least some contact with developments in science and technology and their relationships with society is evidenced by the popularity of these media offerings. The New York Times publishes a weekly section on science. Science '80, the new popular journal of the American Association for the Advancement of Science, achieved a circulation of 400,000 during its first six months. The Public Broadcasting Service's (PBS) NOVA consistently achieves viewer ratings that are among the highest of PBS's adult program series. If planteria and zoos are included, attendance at science and technology museums outnumbers attendance at all other types of museums combined. Roughly 40 percent of the total U.S. museum attendance is to science museums. The Smithsonian Institution's National Air and Space Museum has an annual attendance of ten million, approximately the same as Disney World. The National Museum of Natural

History and the Chicago Museum of Science and Industry both have annual attendances of about five million.[16/]

Little is known about the extent to which exposure to these informal educational opportunities leads to genuine comprehension of science and technology or stimulates more systematic study in these areas. Nor have these opportunities been exploited in any systematic way as adjuncts to the formal education system. Given their evident appeal, however, it would be worthwhile to explore ways to use these media more effectively to increase overall public understanding of the processes of science and technology, and also to extend their scope to reach broader segments of the American public.

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SECTION V. SCIENCE AND MATHEMATICS EDUCATION AT THE SECONDARY SCHOOL LEVEL*

A. INTRODUCTION

The Nation's elementary and secondary educational system has traditionally been regarded as an essential vehicle for achieving two broadly defined sets of social goals, consistent with the ideal of universal education:

- To provide to all citizens knowledge and training consistent with their individual abilities, and opportunity for the fullest possible individual growth and development to allow them to function effectively in a variety of pursuits; and

- To translate, into practice, Thomas Jefferson's familiar dictum that an enlightened citizenry is the only safe repository of the ultimate processes of society.

The system that is called upon to fulfill these tasks is highly pluralistic and politically diffuse. It consists of approximately 17,000 individual school districts, each of which has primary control over standards, curricula, and budget allocations for faculty salary, facilities, and equipment.

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* A detailed discussion of the information base used for this section appears in Appendix A-4.

During Fiscal Year 1981, State and local governments will expend nearly $100 billion for elementary and secondary education, compared with a proposed Federal Government budget authority of $9.4 billion for elementary, secondary, and vocational education. Yet, changing demographic and funding patterns are placing considerable stress on the system. Secondary school enrollments, which peaked in 1971, have been declining and are expected to continue to do so at least until 1990. This has led to retrenchments which have been most severe in those regions of the country that are also experiencing population losses due to geographical shifts.

The public school system--particularly its secondary education component--is experiencing these pressures at a time when it is being called upon to translate the broad goals noted above into contemporary terms for science and mathematics by carrying out the following tasks:

o Generate a sufficiently large pool of people, adequately educated in science and mathematics, from which may be drawn: (a) the relatively few talented and committed students who will go on to become professional scientists and engineers; (b) future nonscience professionals such as lawyers, journalists, and managers who will require considerable levels of sophistication in scientific and technological matters; and (c) future technicians and members of the skilled work force who will pursue their occupations in an increasingly technological economy.

o Provide all students with sufficient access to education in science and mathematics to allow them to pursue these different career options.

o Equip all students with a sufficient understanding of the concepts and processes of science and technology and the relationships among science, technology, and society so that they can function as informed citizens in our democracy.

The materials presented in the subsequent parts of this section lead to the conclusion that the secondary school system is currently not carrying out these tasks adequately. Other industrialized countries, including Great Britain, France, the Federal Republic of Germany, Japan, and the Soviet Union, attach considerable importance to science and mathematics education and are striving to attain a high level of technical competency in the general population (Appendix B). However, in the United States:

o There is a large discrepancy in the amount of science and mathematics training and skill acquired by those who are interested in science and engineering careers and those who are not. While there has always been such a discrepancy, the evidence indicates that in recent years it has been widening. The relatively few students who have a strong interest in the possibility of science or engineering careers are studying and learning as much science and mathematics as they ever did. However, the larger body of students are ending their study of these subjects at an increasingly early stage and are performing less and less well on achievement measures (Section V-B).

o This discrepancy is being reinforced by a general lowering of standards and expectations. Requirements in science and mathematics for high school graduation are low. Some colleges and universities are lowering standards of admission and retention in an effort to compete for a diminishing supply of students, and the amount of remedial work being offered by institutions of higher education has been increasing. The focus of the school curriculum on basic skills has led to an excessive narrowing of curricula. Science is not defined as a "basic" and in mathematics it means mechanistic computational skill (Section V-C).

o The key instructional resources--curricula and teachers--are presently inadequate. There is a mismatch between the content of the curriculum and the needs and interests of the large numbers of students who do not plan to become professional scientists and engineers (Sections V-D and E).

o A shortage of mathematics and physical science teachers and the erosion of teacher support systems weaken the capacity of the system to provide quality instruction to all students (Section V-D).

The remainder of this section discusses evidence for these findings under four headings: Secondary School Student Participation and Achievement; Coursework Requirements and Standards; The Condition of Teachers of Science and Mathematics; and Secondary School Science and Mathematics Curricula and Programs.

B. SECONDARY SCHOOL STUDENT PARTICIPATION AND ACHIEVEMENT IN SCIENCE AND MATHEMATICS

This section reviews the evidence regarding secondary school student attainments as measured by achievement test scores and participation as reflected by enrollments in science and mathematics courses. The main conclusion that follows from the available evidence is that there is a wide divergence in the amount of science and mathematics training acquired by those who are interested in science and engineering careers and those who are not. While some students are getting more and more advanced experiences in secondary school science and mathematics and performing well on achievement measures, there is a large body of students who stop their study of these subjects at a relatively early stage and perform less well on those measures. Moreover, in recent years the divergence is widening.

Achievement

The decline in achievement test scores has been the subject of considerable discussion and debate. Harnischfeger and Wiley, reviewing data on the commonly used tests, conclude that since the mid-sixties, achievement test scores have been declining in all tested areas for grades 5 through 12, with the most dramatic drops occurring in recent years and being most evident for higher grades. These investigators assert that the changes are not artifacts (e.g., do not arise from differences from year to year in test content or scale) and that they do represent a national phenomenon.[1/]

Jones confirms the general picture of modest decline in science and mathematics achievement for the Nation's youth from the mid-1960s to the late 1970s.[2/] He notes that for national samples from the National Assessment of Educational Progress, exceptions to the mean performance decline occur in mathematics for 9-year-olds, where performance was stable, and in biology, ages 9 and 13, where mean performance increased between 1973 and 1977. Thus, the science declines were in physical science for 9-, 13-, and 17-year-olds, and in biology for 17-year-olds.

When the 1978 National Assessment of Educational Progress results for mathematics are compared with the 1973 results, overall performance of 9-year-olds and 13-year-olds declined slightly while there was an appreciable decline for 17-year-olds.[3/] A review of performance on specific test items revealed that students at all levels can add, subtract, and multiply whole numbers about as well as they always have, but there is a sharp decline in their ability to deal with any item that requires understanding and interpretation beyond the rudimentary arithmetic skills.[4/]

White males generally performed better than females or minorities on the national assessments of science and mathematics. There is evidence that women are improving on these measures but still lag behind men. Moreover, various measures of socioeconomic status are highly related to performance. For example, 9- and 13-year-old Blacks living in advantaged urban areas achieve near or above the overall performance of their contemporaries nationwide.[5/]

While this general decline in science and mathematics has been heavily documented, there is also evidence that it is taking place primarily among those who are not planning careers in science and engineering. In fact, there is little average change in achievement for the high school students who elected to take Advanced Placement Tests in science or mathematics.[6/] These students almost always intend to major in science or engineering fields. Analysis of SAT scores reveals a similar picture; those who are the best seem to be learning about as much as they ever did, while the majority of students learn less and less.

In summary, there has been a decline in average science and mathematics achievement for the Nation's youth over the last 15 years. Performance remained stable for the best students. In science, the declines have been more pronounced in physical science than in biology. In mathematics, the declines have been more pronounced on exercises involving application of concepts and problem-solving than on those involving simple computation with whole numbers. White males generally performed better than females and minorities.

In attempting to explain the declines, the Advisory Panel on the Scholastic Aptitude Test Score Decline estimated that between two-thirds and three-fourths of the SAT declines between 1963 and 1970 can be accounted for by compositional changes in the mix of the SAT-taking group. However, the panel concluded that this factor played an insignificant role in the decline from 1970 onward. It suggested a number of other factors that might be responsible for the decline, including a diminished seriousness of purpose in the learning process, grade inflation, and generally lowered standards, and a diminution of learning motivation among students.[7/] Harnischfeger and Wiley argue[8/] that, a priori, one of the strongest contributors to test-specific pupil achievement ought to be the curriculum exposure. A discussion of changing enrollment patterns for science and mathematics courses follows.

Participation

Welch's examination of available data for four time periods shows that about 48 percent of grade 9-12 students were enrolled in at least one science class in 1976-77. This is considerably below the peak of over 59 percent in 1960-61, but is close to the figures for 1972-73.[9/]

Using some of the same data sources, Terleckyj considered both science and mathematics enrollments in grades 7-12 and added another time period. He reports that the proportion of these students enrolled in science courses peaked in 1970-71 at over 69 percent, and declined to 67 percent in 1972-73.[10/] The figures of Welch and Terleckyj are consistent when adjustments are made for grades 7 and 8 and, taken together, lead to the finding that the decline in the proportion of students enrolled in science (that shows up first in 1972-73 and persists to 1976-77) was greater for senior high school students than for junior high school students.

This finding is corroborated by Harms, who considered the distribution of total secondary school students' exposure to science from 1977 data.[11/] In grades 7-12 there were approximately 17 million students enrolled in science classes in 1977. Of these science enrollments, over 80 percent were in grades 7 through 10. Nearly all those enrollments were in courses which attract general student populations. About one-half of the student time reflected by these enrollments was spent in the life sciences, about one-fourth in the physical sciences, and about one-fourth in the earth sciences. After grade 10, the situation changed dramatically. Enrollments in chemistry and physics, the two engineering preparatory courses, accounted for only 6.9 percent and 3.1 percent, respectively, of total secondary science enrollments.[12/]

The proportionate decline in secondary school mathematics enrollments is similar to that for science. Looking more closely at enrollments in specific types of mathematics courses between 1972-73 and 1976-77, Fey reports that some students are getting more and more advanced mathematical experiences in high school while a large body are electing to stop their high school mathematics preparation after 10th grade geometry.

Students enrolled in chemistry, physics, and advanced mathematics are largely college bound, although not necessarily for degrees in science or engineering. Of the students who take no more science or mathematics after grade 10, some go on to college but few can pursue careers in science and engineering since they do not have the prerequisite normally required by colleges for such study. This conclusion is supported by the data from Project Talent showing that once a student drops out of a science and mathematics track at any level, he or she is unlikely to reenter.[13/]

About one-third of the three million high school seniors of 1979 participated in the College Entrance Examination Board's Admissions Testing Program, which includes the Scholastic Aptitude Test (SAT). These latter students generally reported themselves to be in the top part of their class with 70 percent in the highest two-fifths. On the average, SAT-takers reported having taken 3.44 years of mathematics and 3.16 years of science (biological and physical) in grades 9 through 12 and this represents a slight increase from 1973 levels.[14/] From this we can infer that about one-sixth of high school graduates have taken junior and senior level courses in science and mathematics. From the enrollment patterns cited earlier, we can conclude that one-half of all high school graduates take no mathematics or science beyond the 10th grade and only one-half of the students entering college have had any significant exposure to physical science or advanced mathematics beyond the 10th grade.

Conclusions

When combined, the course enrollment patterns and achievement data discussed earlier indicate relatively few students who have strong interest in the possibility of science or engineering careers are learning as much science and mathematics as they ever did--perhaps even more. However, many more students are ending their study of these subjects at increasingly early stages and are scoring less and less well on achievement measures. There has always, of course, been a large discrepancy in the amount of science and mathematics training acquired by those who are interested in science and engineering careers and those who are not, but the data show that in recent years that division has been widening.

C. COURSE WORK REQUIREMENTS AND STANDARDS

About three-fourths of young people today are earning high school diplomas and this proportion has remained relatively constant over the past decade. In contrast, in the early 1930s, only about one-third of pupils completed the 12th grade, and in the early 1950s, slightly more than one-half. Increasing proportions of minority (Black and Hispanic) students graduate from high school but those proportions still lag behind the rate for White students. Increased graduation rates are accompanied by the phenomenon of fewer students being held back in school, although there are significant differences in progression through school related to family income, education level of parents, and racial/ethnic characteristics. Progression rates for Black and Hispanic children are below that for the total population.[15/]

Since about 1970, a trend to reduce coursework requirements for high school graduation has been noted.[16/] School districts are likely to require more courses in social studies than in mathematics or science for high school graduation. Three-fourths of school districts required more than one year of social studies in grades 9 through 12 for high school graduation, compared to one-third that stipulated more than one year in mathematics or science.[17/]

As fewer students are held back and requirements are reduced, there is mounting public concern that some children are being passed through the system without acquiring the expected skills. By a sizeable majority, public opinion favors the requirement of passing an examination as a condition for grade promotion. In response, 36 states have introduced minimum competency testing as a requirement, and 17 of those states plan to use competency testing as a basis for high school graduation. It is also interesting to note that while concerned about progress through school being related to achievement, public opinion rejects the notion of retaining a child in a grade he or she has failed and favor (81 percent) special remedial classes over repeating the grade.[18/]

The concern about declining achievement and assuring minimal competency has led to a focusing of the school curriculum on basic skills. While this focus is primarily at the lower grades, there is evidence that teachers and committees purchasing textbooks are so sensitized to reading difficulties that they are acquiring textbooks in the content fields taught in the higher grades that have a simplified vocabulary and sentence structure. In mathematics, the situation is similar. Schools are demanding textbooks that concentrate on drill and computation at the expense of common applications even in the higher grades. It is not clear that such practices are warranted. Tests show that children have mastered the basic techniques of reading, but have trouble with comprehension and interpretation. Similarly, children can do simple whole number computations, but have trouble solving common problems.[19/] This concern is also expressed by many organizations associated with education.[20/] As the National Congress of Parents and Teachers noted:

> "Though emphasis on acquiring basic skills is at the heart of the educational process, there is a distinct possibility of basics becoming <u>the</u> curriculum rather than just <u>part</u> of the curriculum. Another problem, with an overemphasis on basics, is a tendency to teach children only those things for which they will be tested, a tendency that leads to mediocrity."

The focus on basics is having an impact on science teaching, particularly in the elementary grades. This is because science is not viewed as "basic" by the general population or educators. As a result, what little attention science had been given in the elementary grades is diminishing.[21/]

The minimal competency movement and the associated focus of school instruction on basic reading and arithmetic skills clearly arises from a broad national concern about the quality of education. While there is a need to assure that all students achieve minimum proficiency in these areas, there is also a need for a common understanding that minimal competency should not displace attention to the development of their ability to deal with more varied and complex materials and problems in the content subjects.

Another related reason for relatively low participation and declining achievement levels in science and mathematics--even among the college-bound--may well be the reduction of standards for admission and retention by some colleges and universities in response to increased competition for students. The final report of the Carnegie Council on Policy Studies in Higher Education concluded that the diminution of college entrance and retention requirements has had adverse effects on academic standards at the high school level. As a result of this conclusion, the Council recommends that each college and university should revert to the admission and retention standards of 1960.[22/] A recent study by the Conference Board of the mathematical sciences shows that enrollments in courses below calculus in four-year colleges and universities increased by

10 percent between 1970 and 1975, while the number of first-time students in these institutions increased only 2.7 percent. In two-year colleges, high school-level mathematics courses accounted for 36 percent of all mathematics enrollments in these institutions in 1975, compared with 26 percent in 1966 and 29 percent in 1970.[23/]

Even secondary school students enrolled in science courses appear to have some doubts about the value of the experience. In 1977 the National Assessment of Educational Progress surveyed attitudes of 9-, 13-, and 17-year-olds about their science courses. Three-fourths of the students felt that their science courses were useful. However, slightly more than half that number believed the things they learned in science classes would be more useful in the future than to their everyday life, and two-thirds of the 13-year-olds either did not plan to take more science or were uncertain about whether to do so. More than half of the students replied that their science courses were too difficult; 21 percent of the 13-year-olds and 31 percent of the 17-year-olds regarded their science courses as boring. Yet, according to the survey, three-quarters of the 13- and 17-year-olds surveyed felt that science would *eventually* be important, even though many found their courses difficult or boring to them. Two-thirds felt that science ought to be required even though many planned to take no further science courses. These data suggest that noncareer-bound and noncollege-bound students *might* be motivated to take additional science and mathematics and might attain higher levels.[24/]

Finally, avoidance of upper level science and mathematics by a large majority of secondary school students could be due in part to a lack of realistic career information for students, teachers, guidance personnel, and parents. Students have few resources on which to base a judgment about what types of work activities are associated with various science and mathematics coursework, or about which of them hold the best promise for career entry and future advancement. As a result, many important decisions about choice of courses are made on the basis of hearsay and intuition. While we were unable to uncover a systematic documentation of this matter, concern about school counseling has been persistent and widely articulated.

These tentative conclusions relating declining achievements to a relaxation of standards and a diminution of student motivation for learning were buttressed by the identification, by the panel, of sixty high schools throughout the country whose college-bound seniors had stable SAT test scores from 1963 to 1970 and some tendency for scores to rise from 1973 to 1976. These schools placed greater emphasis on traditional academic programs than a group of similar schools with declining test scores.[25/]

D. THE CONDITION OF TEACHERS OF SCIENCE AND MATHEMATICS

Recent studies confirm the conclusion that classroom teachers play a pivotal role in the education of students.[26/] While teachers do not bear total responsibility, they do have a great deal of freedom and discretion in determining what the content of their courses will be. In addition, it has been noted that science and mathematics teachers play an important role in motivating students in relation to their achievement levels in the courses they teach and in their decisions about whether to take more advanced courses in science and mathematics.[27/] Given the central importance of teachers, two factors are cause for concern.

First, there is presently a significant number of unfilled teacher positions in mathematics and physical science at the secondary school level. In response to perceptions that there are few openings for new teachers, the number of people seeking entry to teachers colleges' and universities' educational preparation programs has decreased markedly. A national survey found that at the end of the 1977-78 school year, almost 10 percent of the mathematics teaching positions in the secondary schools of the United States were vacant.[28/] The 200 secondary school mathematics supervisors who responded to this survey consider this to be a moderate demand for teachers. Furthermore, their five-year projections do not expect this situation to change. Separate surveys have confirmed shortages of mathematics teachers in Indiana[29/] and Missouri.[30/] There is a similar, but apparently smaller, number of unfilled positions for competent new physical science teachers as well.[31/] In addition, some observers believe that the quality of new mathematics and science teachers has declined.[32/]

Unfilled teacher positions in mathematics and physical science evidently result both from a lessening in the attractiveness of science and mathematics teaching careers and from opportunities for more desirable employment outside of teaching, because the supply of degree-holders with majors in these fields is high. For example, the National Education Association reports that the average salary for beginning teachers with a bachelor's degree in 1978-79 was 73.1 percent of the average beginning salary offered in 1978 by private industry to bachelor's degree graduates in mathematics-statistics. In 1975-76, this ratio was 79.7 percent.[33/] It is widely known that when positions cannot be filled through new hiring of qualified instructors, they are often filled by teachers with lower subject matter qualifications or by the transfer of tenured teachers from other subject areas. Thus, inevitably many secondary school mathematics and physical science teachers have insufficient training to teach courses in these subjects. This conclusion is reinforced by data from a nationwide survey which indicated that a sizable number of secondary school science and mathematics teachers feel inadequately qualified to teach one or more of their courses.[34/]

The second factor causing concern is the erosion of support systems for teachers. Supervision at the secondary level has been reduced as a result of financial retrenchment or has been shifted to administrative tasks from instructional support. There are relatively few people available outside the classroom to provide quality control and assist teachers with pedagogical problems.[35/] The teachers, however, clearly want this help. A total of 67 percent of science, mathematics, and social studies teachers reported needing assistance in obtaining information about instructional materials[36/] and over one-half of these teachers said they needed help from laboratory assistants or paraprofessionals.[37/]

The use of the laboratory is widely considered essential for adequate instruction in science and over 25 percent of school teachers and administrators consider inadequate facilities as a serious problem for science. However, there is evidence that teachers may not make frequent use of them even when available.[38/] It is likely that there is a threshold phenomenon involved. For example, the best equipped laboratory may not be used if paraprofessionals or aides are not also available, especially because safety has become an increased concern in the schools. In any case, very little use is made of out-of-school facilities such as nature centers, museums, and planetaria. The reasons for this are unambiguous, but transportation problems and chaperonage appear to be important factors.

Another facet of the erosion of support systems for teachers is a decline of opportunities for faculty development.[39/] There has been a sizable drop of Federal support of summer and in-service teacher institutes since the peak funding years of the late 1960s, and this support has not been replaced by local sources. One specialist who made an extensive evaluation of the summer institute program concluded that it was generally successful in making a significant, positive impact on secondary school science and mathematics education. However, it seems few of the least qualified teachers have applied for institute participation.[40/]

In addition to providing continuing educational opportunities to science and mathematics teachers, summer and in-service institute programs provided an important incentive to secondary school teachers by allowing them to associate with their school, college, and university peers and learn from the experience of others about improved teaching and curriculum approaches.[41/] The reinstitution of such opportunities for sustained interaction between secondary school and university science and mathematics faculty would, in the opinion of the participants at a National Research Council seminar, help improve coordination between secondary school science and mathematics and other components of the science and engineering education system. It was the consensus of the seminar participants that the quality of education at all levels would be improved by such integration. Other effective steps could include continuing educational opportunities for secondary school teachers in industry; and programs, including curriculum development, involving college and university faculty more intimately in the secondary schools. In particular, the seminar participants suggested there may be reasonable numbers of university science and engineering faculty who are retired or near retirement who would be enthusiastic about such involvement.[42/]

E. SECONDARY SCHOOL SCIENCE AND MATHEMATICS CURRICULA AND PROGRAMS

Federally sponsored curriculum development programs were an important strategy for improving science and methematics teaching in the post-Sputnik era. At least initially, the focus of these programs was the motivated, college-bound student, though not necessarily those intent on careers in science and engineering. A 1977 survey of textbooks commonly used in secondary school science and mathematics courses revealed that, except for biology courses, relatively few schools presently use the products of these national development programs.[43/] However, Welch contends the programs and materials produced had a marked effect on the quality of non-Federally supported text development. The availability of good, contemporary course material has had a generally positive effect on the quality of preparation of the relatively small numbers of secondary school students who pursue careers in science and enginering.[44/]

Unfortunately, relatively little attention has been paid to curricula for those who are not intent on such careers. Recent studies of the status of pre-college science and mathematics education and analysis of the content of commonly used textbooks and other literature lead to the conclusion that, at present, the content of science courses in both junior and senior high schools gives extensive and almost exclusive attention to preparation for future coursework leading to professional careers in science. The emphasis is heavily on the pure "structure of the discipline" form of science. Very little in the content of courses provides information related to personal or societal problems, about technology and what engineers do, or to vocational relevance except to those students interested in professional science careers.[45/]

Nine organizations[46/] view this situation with concern. The National Science Teachers Association puts it this way:

> ...much of the secondary school science curriculum is mismatched to the interests and needs of the majority of students in our schools who will not pursue scientific or technological careers.[47/]

This mismatch to needs is paralleled by a mismatch to stated intent. While broader purposes for science education are often stated, they are rarely addressed in practice.

There are some notable exceptions to the prevalent discipline-oriented courses. Environmental science courses approach the study of science by focusing on problems of personal and social concern. One physics course developed under a Federal curriculum development grant approaches the discipline by placing it in its social and historical context.[48/] Another Federally supported curriculum stresses the relationships between technology and science.[49/] Such courses focus on concepts, processes, and relationships to other fields rather than trying to teach students to view science from the perspective of an academic research scientist. There is at least some evidence that courses such as these do attract students who do not have a strong interest in science but who are at least academically motivated,[50/] even though few of these courses are widely used at present in secondary schools.[51/]

Several contributors to this review,[52/] and the participants at a National Research Council seminar arranged in conjunction with it,[53/] stressed the need for greater flexibility in secondary school science and mathematics programs to suit the interests and needs of diverse student populations. This view is shared by many others.[54/] One contributor urged restructuring of the secondary school curriculum to be undertaken in the light of the opportunity afforded by calculators and computers.[55/] He argues that these technologies make possible a new organization of material, new motivations, new applications, alternative pedagogic strategies, stronger interrelationships between different fields and different parts of the same field, and better connection of mathematics and science to the real world. He also points out that there have been, in recent years, many experiments at specific grade levels and with particular pieces of subject matter, but argues for a global analysis of the problem across grade levels and across the total subject matter of elementary and secondary education.

In addition to stressing the need for substantial curriculum reform, Gordon also recommends more fundamental structural reform in the secondary school system as necessary to address the challenges posed by science and technology.[56/] Basing her paper on a 1979 report of the Carnegie Council on Policy Studies in Higher Education, she notes that a total school environment is not congenial to many students during their late teens. She therefore recommends the introduction of alternatives, including work-study and internship programs.

Gordon also stresses the needs of the academically motivated by recommending the establishment of more academically oriented high schools and special programs within existing schools. The desirability of focusing more attention on talented students with special interests in science and mathematics was also stressed by Lapp[57/] and several commentators on an early draft of this review.[58/] These commentators contend this would raise the overall level of understanding of science and mathematics, preserve the potential pool of scientists and engineers by avoiding the premature foreclosures of choice, and provide a base of knowledge so people could much more easily return to science and engineering pursuits at a later point in their education.

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VI. APPENDICES

APPENDIX A

TECHNICAL NOTES

Bureau of Labor Statistics (BLS) Projections of 1990 Employment (Section II-B)

The BLS developed its projections for 1990 employment of scientists and engineers in a series of steps that linked aggregate economic activity to output by industry to employment by occupation. The first step started with assumptions covering the expected conditions of economic growth and Federal policy goals. In one set of projections, it was assumed that the Federal budget deficit would decline after 1980, reaching a level near $20 billion in 1990. For an alternative projection, BLS assumed that the budget would be balanced by 1983 and remain so through 1990. The unemployment rate was assumed, for all projections, to decline to 4.5 percent in 1990, whereas productivity per worker was assumed to rise annually at rates near the 2.6 percent level achieved between 1955 and 1968. BLS projected the 1990 labor force using the Series II population forecasts of the Bureau of the Census.

An econometric model was used with these assumptions to project the aggregate economy and to distribute the Gross National Product by category of demand. There are four such major categories: personal consumption expenditures, gross private domestic investment, net exports, and government purchases. Each component of demand was in turn broken into purchases made from 160 different industries, including, for example, dairy and poultry products, coal, and paper products.

In the next step, purchases from these 160 industries were introduced into an input-output model that had been adjusted to reflect projected 1990 production processes. This model is a large matrix (160 by 160) that tells what goods and services each industry buys from all other industries to produce its output. For example, the automobile industry purchases inputs from the steel, plastic, glass, rubber, electronics, and many other industries. This step generated outputs for each of the 160 industries.

For the final step linking outputs to employment, a labor demand model was used to project productivity, hours, and employment at the level of each industry. A matrix that distributes employment in each industry by detailed occupation was then used to estimate total 1990 employment in each of 380 different job categories. Only science and engineering occupations are reported here.

For more information, see BLS Bulletin 2030, Employment Projections for the 1980s.

National Center for Education Statistics (NCES) Projections of Baccalaureate and Master's Degrees in Science and Engineering (Section II-B)

The NCES estimated future degrees on the basis of its projections of college and university enrollments. The first step in the projection process was to calculate the percentage of the population enrolled in higher education in each of several recent years in each of several age groups. These percentages were projected into the future for each age group. The statistical method used to estimate future enrollments, exponential smoothing, places more weight on recent observations than on earlier ones.

Bachelor's and master's degrees were projected on the basis of their past statistical associations, as indicated by regression analysis, with undergraduate and graduate enrollments, respectively. Awards at these two levels were distributed among the science and engineering and other fields on the basis of past trends and statistical relationships.

For more information, see Projections of Education Statistics to 1988-89 (in preparation).

National Science Foundation (NSF) Projections of the Supply and Utilization of Doctoral Scientists and Engineers (Section II-B)

Estimates of the 1990 science and engineering Ph.D. market were adapted from the publication, Projections of Science and Engineering Doctorate Supply and Utilization: 1982 and 1987 (NSF 79-303), which was prepared in 1978. It was assumed that the annual changes in Ph.D. supply and employment projected for the period 1977-1987 would continue through 1990.

To generate the utilization figures reported in NSF 79-303, NSF used econometric modeling and trend extrapolation to estimate the number of science- and engineering-related positions that may be available by field for doctorates in 1978. NSF projected the two largest categories of science and engineering employment, academia and industrial research and development, through the use of demand equations that were derived from regression analysis. These equations related employment to demand variables such as research and development spending and the number of science and engineering baccalaureates awarded (an index of teaching loads) in a year. Other categories of science and engineering employment in government, nonprofit organizations, and industry (other than research and development) were projected through extrapolation of past growth trends.

To generate estimates of 1987 supply by field, NSF used a recursive econometric model that reflects the relation between the Ph.D. labor market and the number of doctorate graduates. In this model, poor employment opportunities in a given year result in lower graduate school entrance and completion rates, and hence in fewer graduates in future years, whereas better market conditions induce higher rates, and hence more future graduates. Projected market conditions depend upon the interaction between demand variables and the number of new graduates in each field.

For more information on NSF prediction methods, see NSF 79-303.

Information Base on Pre-College Science and Mathematics Education

(Section V)

The information base available for the review of science and mathematics education in elementary and secondary schools is particularly extensive, since NSF recently sponsored an assessment of the status of the Nation's elementary and secondary school education practices in science, mathematics, and social science. Three complementary approaches were undertaken--survey, case study, and literature review. This aggregate effort is referred to as the Status Study. The results were published in six volumes in 1978. A seventh volume comprising the Status Study overview and summary documents of the three interrelated approaches was also published as follows.

a. Overview and Summaries

- The Status of Pre-College Science, Mathematics and Social Studies Educational Practices in U.S. Schools: An Overview and Summaries of Three Studies.

b. The national survey of teachers, principals, and superintendents regarding training, materials, and educational practice was contracted to Iris Weiss of Research Triangle Institute. The survey findings are reported in one document.

- Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education.

c. The case studies covered eleven in-depth investigations of ongoing educational practices. This study was contracted to Robert Stake and Jack Easley at the University of Illinois, Urbana. The case study findings are available in a two-volume set.

- Volume I: Case Studies in Science Education. The Case Reports.
- Volume II: Case Studies in Science Education. Design, Overview and General Findings.

d. The literature review, contracted to Stanley Helgeson, Ohio State University, examined published and unpublished documents related to existing needs statements in science, mathematics, and social studies. The results of this review are being published in three volumes:

- Volume I: The Status of Pre-college Science, Mathematics and Social Science Education: 1955-1975. Science Education.
- Volume II: The Status of Pre-College Science, Mathematics and Social Science Education: 1955-1975. Mathematics Education.
- Volume III: The Status of Pre-College Science, Mathematics and Social Science Education: 1955-1975. Social Science Education.

To help make the nearly 2,000 pages of materials in these seven volumes more accessible and useful for different audiences and for policymakers, NSF invited nine organizations to analyze the studies independently and write reports. These nine reports are not only descriptive, they are also normative. Each organization was asked to extract from its analysis the major needs in science education from the point of view of its membership. Thus, collectively, the reports give an idea of what problems and issues are thought to be most important, what the system's strengths and weaknesses are believed to be, and what the most important strategies for improvement might be. Although the formats for each report differ, they all contain, either explicitly or implicitly, a set of recommendations for the improvement of science education.

These nine reports have been published in a single volume (available July 1980) under the title:

- What are the Needs of Precollege Science, Mathematics and Social Science Education? Views from the Field.

All of this material was available to most of the persons who contributed to or were involved in this review. This great wealth of information does not lead immediately and directly to an inevitable set of conclusions as multiple interpretations are always possible especially when normative factors are brought to bear. Nevertheless, the content of Section V of this review represents a reasonable consensus of the views expressed in the light of the available information.

In addition to these sources, NSF has recently issued the Science Education Databook, which is a compendium of quantitative information portraying science education in the United States. It contains information collected from a wide variety of sources that are described in an annotated bibliography.

APPENDIX B

INTERNATIONAL COMPARISONS IN SCIENCE AND ENGINEERING EDUCATION

There has been some concern about the relative trends in the production of scientists and engineers in the U.S. as compared with other highly industrialized countries. This concern centers on the important question of whether the U.S. faces a reduced ability, relative to other countries, to generate and incorporate technological change in its production and utilization of goods and services.

Comparisons between the U.S. and our international competitors suggest that our eminence in basic research is secure (Section II-D).[1/] However, our ability to apply technology to our military and industrial pursuits may well be hampered by the relatively low level of scientific and mathematical competence of our nonscientists and, in some respects, by the apparent cooling of science interest among our students generally. For example:

o There is anecdotal evidence from U.S. industry that in some highly technical areas the time required to produce a product has increased as workers' base level of understanding of science and mathematics has decreased over the past decade.[2/]

o The U.S. military complains that it is more and more difficult to find officers and noncommissioned officers who are qualified to be trained to operate the increasingly sophisticated military hardware.[3/]

The body of this review notes some anxiety about two subject matter areas: engineering and the computer professions. While the U.S. has current shortages and future shortfalls in these areas, the Soviet Union, Germany, and Japan are producing much larger proportions of engineers and applied scientists than we are.[4/] At the same time, these countries are educating a substantial majority of their secondary school population to a point of considerable scientific and mathematical literacy, in part because they apparently believe that such literacy is important to their relative international positions. For example:

o The recent Committee of Inquiry into the Engineering Profession in Great Britain (the "Finniston Report")[5/] laid the decline in the ability of Britain to compete in international trade squarely on the lack of vigor of the engineering profession and recommended, among many other things, that "...all pupils should be strongly encouraged to maintain the study of mathematics and physics at least until after 'O' level..."[6/] (national competence exams given at the end of secondary schooling).

o As a part of its analysis of engineering in other countries, the Finniston Report stated that "...the level of education of the average Japanese worker is markedly higher than that of his U.K. counterpart; this applies at all levels of the firm, especially on the shop floor... . The strength of Japanese engineering is in our view partly due to the standard of education of those involved in the engineering dimension at working level."[7/] Though the difference in the level of worker education between Japan and the U.S. is not as broad, there is concern that the same general conclusion may be warranted.

o Regarding Germany, the Finniston Report notes that from secondary school "A student specialising in classics or modern languages...can cope with an engineering degree course because he will have kept up his mathematics and science throughout his period at school."[8/] In other words, even a student who majors in modern languages in secondary school learns enough science and mathematics to be able to attend engineering school and compete with others who have majored in science.

o In the Soviet Union, there are national elementary and secondary curricula in science and mathematics which, in content and scope, surpass that of any other country.[9/]

The import of the last three points is that in Japan, Germany, and the U.S.S.R., national policy promotes the comprehensive science and mathematics education of far greater numbers of people than are expected to engage in scientific and engineering pursuits. In the Soviet Union and Japan, especially, managerial positions in both government and industry are heavily populated by people with engineering degrees.[10/]

Over the past 15 years or so, while British training of engineers fell behind so drastically that a comprehensive inquiry was commissioned by the government,[11/] while Germany and Japan continued to stress science and mathematics for all their secondary students, and while U.S. secondary students not intending to major in science or engineering were choosing to take fewer science and mathematics courses, those countries' share of world trade in manufactured items (excluding food and fuel) changed as follows:[12/]

	Share of World Trade		Engineering Graduates As A Proportion of Relevant Age Group
	1963	1977	(1977-78)
United Kingdom	15%	9%	1.7%
W. Germany	20%	21%	2.3%
Japan	8%	15%	4.2%
United States	21%	16%	1.6%

Between the same years (1963-1977) productivity increased in the manufacturing industries of the United Kingdom, West Germany, Japan, and the U. S. (using 1963 as the base year) by 51 percent, 114 percent, 197 percent, and 39 percent, respectively.[13/]

In considering cross-national comparisons of training in science and engineering one must be cautious, because educational systems are not parallel and often are quite dissimilar. For example, the group labeled "engineers" in one country may include an unknown number of those termed "technicians" in the U.S. Nevertheless, some of the differences in outcome are dramatic.

In Japan, for instance, the number of degrees granted to engineers in recent years has surpassed the number granted in those same years in the U. S., though its base population is roughly one-half of ours.[14/] In Japan, 20 percent of all baccalaureate and about 40 percent of all master's degrees are granted to engineers,[15/] and these figures have been nearly stable for the past 10 years.[16/] This compares with a figure of about 5 percent at each degree level in the U.S.[17/] Japanese education officials point out that students view the engineering degree as a "ticket" to business and social success in much the same way as the liberal arts degree (and now the M.B.A. degree) was viewed in the U.S. two generations ago.

It is reported that only about 50 percent of the engineers produced each year in Japan enter the engineering profession. The others become civil servants and managers in industry. Around one-half of the senior civil service hold degrees in engineering or related subjects, and one-half of those are at the postgraduate level. In industry, about 50 percent of all directors have engineering qualifications.[18/]

The large number of Japanese students who enter scientific fields (65 percent of baccalaureate degrees[19/] vs. 30 percent in the U.S.) is made possible by a secondary educational system which has a heavy emphasis on science and mathematics. There is a national guideline for lower secondary education (grades 7-9) which calls for about 25 percent of the classroom time to be mathematics and science courses, and virtually all students are thus exposed.[20/] In secondary school, nearly all of the college-bound students (roughly one-third of the total) take three natural science courses (physics, chemistry, biology, or earth science) and four mathematics courses (algebra, geometry, calculus, or statistics) during their three-year high school career.[21/]

There has been significant effort in recent years to revise and update the high school science teaching in Japan, and it is now heavily influenced by the U.S. Physical Science Study Committee (PSSC) and the Biological Science Curriculum Study (BSCS) materials. Chemistry has been upgraded by a committee on chemical education set up by the Chemical Society of Japan.[22/]

Mathematics instruction has a more rapid pace in Japan than in the U.S., and a much higher proportion of students take the more advanced courses. Geometry is taught in the 7th, 8th, and 9th grades. Trigonometry is also studied in the 9th grade. Calculus, probability, and statistics are offered in high school.[23/]

The overall quality of this instruction appears to be high. The International Project for the Evaluation of Education Achievement ranked Japanese 13-year-olds highest in mathematical achievement among 12 countries including the U.S. and several European countries. Japanese students were also the most positive in their liking for mathematics.[24/]

In Germany, the general preparation is similar. There is a standard curriculum for all students through the 10th grade, and the only variation is in specialized science-oriented schools where each subject is studied more intensively.[25/]

Science begins in the 3rd grade with biology one to two hours a week, in the 5th grade, chemistry and physics are begun (as laboratory courses). All three sciences are taught two to three hours a week in that grade, and geometry is introduced. The study of algebra begins in the 7th grade. As students progress through the grades, the amount of contact with science and mathematics increases.[26/]

At the end of 10th grade, all students who have an average of about B or B+ (this varies a little by state) may continue to upper secondary schooling--grades 11 to 13. Those whose grades are lower attend vocational school and begin apprenticeships in a variety of pursuits. The students who attend upper secondary school (currently about 28 percent of the 10th grade population, up from only 6 percent ten years ago) declare three major and five minor interests, one of each of which must be a science (which is pursued five hours a week as a major and two to three hours as a minor). Mathematics at the 11th grade level includes algebraic functions and differential calculus. By the end of the 13th grade, students have studied integral calculus, statistics and probability, and vector analysis. At this level, too, those with special interest in science take more intensive courses.[27/]

About 75 percent of the upper secondary graduates go on to universities, and roughly one-third of those pursue a science, engineering, or mathematics degree.[28/]

Thus, the overall picture in Germany is one of a very high level of science and mathematics literacy among college graduates as well as a strong science/mathematics understanding among the general population. This provides them with the basic tools to continue their education (German law guarantees that all people are entitled to a free education to as high a level as they desire) at a later point in their careers, as many choose to do.

The situation in the Soviet Union is less clear. The country has achieved virtually universal education through about the first ten years of schooling. Most of those students (about 60 percent) go on to complete General Secondary School[29/]--grades 9 to 10 (or 11)--and are exposed to a mathematics and science curriculum which, according to one observer, surpasses that of any other country including the U.S.[30/] Algebra and geometry are taught in the 6th and 7th grades, advanced algebra and trigonometry are taught in grades 8 to 10, and calculus, which a total of about 500,000 Americans take during their last year in high school or their first in college, is a part of the high school curriculum for over 5,000,000 Soviet students. In addition, all youngsters are required to complete five years of physics, four of chemistry (including a year of organic chemistry), and up to four of biology depending on whether they attend specialized (i.e., vocational) or general secondary schools.[31/] While students in specialized secondary schools (about 12 percent of 8th grade graduates) are exposed to less science except in specialty fields related to engineering technology, the avowed goal of Soviet educational policy is to ensure that the future labor force will facilitate the transformation of the economy to a scientific-technical base and to supply more technologically oriented people to fill the military ranks.[32/]

About five times as many (with a population base about 1-1/2 times ours) Soviet students as American students go on to engineering training.[33/] In the Soviet Union engineering is considered to be the standard liberal arts education. Moreover, it has been pointed out that though training is variable, at the better institutions the first Soviet degree in engineering represents a content level closer to our master's than to our bachelor's degree.[34/] In other sciences, the Soviet Union produces fewer chemists and biologists than we do, about the same number of physicists/mathematicians, and a few more environmental scientists.[35/]

This picture of engineering, mathematics, and science education in the Soviet Union is not complete; there are some major problems. Secondary school curriculum changes mandated a decade ago have been implemented slowly and have not spread throughout the educational system. The secondary science courses have little laboratory work associated with them and are generally learned by rote. Rural schools tend to be poor. At the university level, science and engineering education is very narrow-gauge; i.e., students specialize sharply at a very early point. The sizable nonRussian-speaking minorities in the country are at a disadvantage because the best university instruction in science and engineering is in Russian.[36/]

There is little specific data, but informed U.S. opinion is that there is widespread underemployment of the science and engineering work force in the Soviet Union. New graduates generally begin at the lowest rungs of the production ladder and work their way up slowly. Perhaps more important, fungibility and mobility in the fields of science and engineering are very low compared with the U.S. A member of the Soviet science and engineering work force is trained almost for a specific job and usually remains with a particular institution for a whole career.[37/] This results in a system that, in the opinion of some, is very slow to rise to new specialities and has a reduced ability to innovate.

Though the problem areas in the education and employment of Soviet scientists and engineers appear to be many, their potential capacity to compete internationally should not be underrated. There are many signs that the inefficiencies are being recognized and the Soviets' general acceptance of the legitimacy of science and engineering pursuits provides a context in which quality may well improve very rapidly.

For all of these countries, it is difficult to separate the effects of government policy, market factors, and social pressures. What is clear is that in each case there is a strong national commitment to quality science and mathematics instruction as an essential part of the pre-college educational process. The result is a work force which, at all levels, has a relatively high degree of science and mathematics skill, and this has been a factor in the very rapid expansion of technical industries.

REFERENCES -- APPENDIX B

1. In 1977 (the most recent year available), the U.S. produced 38 percent of the world's scientific and technical articles. Moreover, U.S. scientific and technical literature was cited in non-U.S. articles at a rate 15 percent higher than could be expected from the U.S. share of the world literature. These two indicators have stood at virtually the same level since at least 1973. See pages 150 and 152 of <u>Science Indicators 1978</u>, Report of the National Science Board, 1979.

2. As far as could be determined, there is no written substantiation of this comment, but the point has been reported from several separate conversations. Because of its "softness," it would not have been included here except that it links two widely observed phenomena (decrease in U.S. worker productivity and decrease in students' general levels of understanding of science and mathematics) in a way which is consistent with similar concerns in Japan and the Soviet Union.

3. Submissions of both the Department of Defense and the Air Force (Appendix D-4) emphasize the twin problems of recruiting and retaining technical personnel and the "close to revolutionary" pace of technological advance which draws on new disciplines which, according to the Air Force, will "have to be widely represented among USAF military and civilian personnel very soon." In the "Summary of Briefings" attached to the Air Force submission, it is pointed out that "All Soviet active duty pilots receive a highly intensive technological education even though they rarely serve in other than operational assignments."

4. Engineers far outnumber applied scientists in each of the countries named. In recent years the number of engineering graduates as a proportion of the relevant age group has been approximately 6.5 percent for the U.S.S.R., 4.2 percent for Japan, 2.3 percent for Germany, and 1.6 percent for the U.S. If it is assumed that one-half of all new mathematics and physical science graduates in the U.S. (1.16 percent of their age cohort) and all new computer professionals (0.25 percent) enter applied fields, the maximum total proportion of new engineering and applied science graduates relative to their age group in this country is 2.43 percent. This is comparable to the rate for Germany, which has 2.3 percent engineers and an estimated 0.25 percent for new applied scientists.

5. <u>Engineering Our Future</u>. Report of the Committee of Inquiry into the Engineering Profession. Her Majesty's Statement Office, London. January 1980. (This commission was chaired by Sir Montague Finniston and its report is commonly referred to as the "Finniston Report.")

6. <u>ibid</u>, p. 50.

7. <u>ibid</u>, p. 209.

8. <u>ibid</u>, p. 219.

9. From an unpublished paper by I. Wirszup. The description of the scope and quality of the Soviet secondary science and education has been substantially corroborated by conversations with Dr. Nicholas DeWitt, Dr. Murray Feshbach, and by information contained in "A Summary Report on the Educational Systems of the United States and the Soviet Union: Comparative Analysis" prepared by SRI International for the National Science Foundation. March 1980. (Appendix G).

10. Information about Japan is taken from the Finniston Report, op. cit., Note 5, pp. 211-212. Information about the USSR is from conversation with Dr. Thane Gustafson, The RAND Corporation.

11. The Finniston Committee was formed in July 1977.

12. Shares of World Trade appear as Table 1.3 on page 11 of the Finniston Report (Note 5). Engineering graduate information is from Table 4.1, p. 83, of the same report.

13. Adapted from Table 1-15, p. 156, of Science Indicators 1978, op. cit., Note 1.

14. Japanese information from Statistical Abstract of Education, Science and Culture published by the Ministry of Education, Science and Culture, Tokyo, 1979 edition. U.S. information from Earned Degrees Conferred, yearly series published by the National Center for Educational Statistics, Department of Health, Education, and Welfare (DHEW), 1980 edition.

16. Adapted from Table 3, pp. 72-75, Japanese Statistical Abstract of Education, Science and Culture.

17. op. cit., Note 14.

18. This description is given in the Finniston Report, op. cit., Note 5, pp. 211-212.

19. Statistical Abstract of Education, Science and Culture, Table 3, op. cit., Note 5, pp. 72-75.

20. From Education in Japan, U.S. Office of Education, 1974, corroborated and updated by conversation with Mr. Wada, the Education Attache, Embassy of Japan.

21. ibid.

22. op. cit., Note 20.

23. ibid.

24. ibid.

25. Copies of secondary school lesson plans for mathematics, chemistry, and physics, supplemented by conversation with Mr. Horst Breckwoldt, Principal of the German School in Potomac, Maryland, and Ms. Dorit Geurtsen-Bandmann, Director of Guidance at the same school.

26. *ibid*.

27. *ibid*.

28. *op. cit.*, Note 25.

29. Nicholas DeWitt, "Summary Findings: The Current Status and Determinants of Science Education in Soviet Secondary Schools." (NRC Paper, Appendix D-1).

30. *op. cit.*, Note 9.

31. *op. cit.*, Note 9, p. 3.

32. *ibid*, p. 5.

33. This varies a bit depending on which year is used for the comparison. Table 8, p. 29, of the SRI International report (Note 9) presents figures from 1960 to 1977.

34. *op. cit.*, Note 29. However, SRI International (Note 9) expresses slightly different opinion regarding the few engineering specialties which have been directly compared.

35. *op. cit.*, Note 9, p. 30 (Table 9), and p 33 (Table 12).

36. Conversation with Dr. Thane Gustafson corroborated by conversation with Dr. Murray Feshbach.

37. Conversation with Dr. Thane Gustafson, partly corroborated by information from the Soviet Desk, U.S. Department of State.

APPENDIX C

MINORITIES, WOMEN, AND THE PHYSICALLY HANDICAPPED IN SCIENCE AND ENGINEERING

Equality of opportunity is a keystone of Federal educational policy. Although the problems facing minorities, women, and the physically hand capped in science and engineering education are in many respects different, the common thread that ties them together is that of overcoming barriers to equality of opportunity.

In each case the Federal Government plays an important role in moving toward the objective of equality of opportunity. The role is expressed through court decisions (e.g., Brown vs. Board of Education), public laws (e.g., P.L. 94-142, the Education of All Handicapped Children Act), grant and fellowship programs (such as the Graduate and Professional Opportunities Program, which particularly supports women and minorities studying science and engineering), Federally funded public television programs (e.g., 3-2-1 Contact, a science series for 8- to 12-year-olds emphasizing opportunities for minorities and women in science and technology), and through a variety of other means as well.

Status of Minorities in Science and Engineering

1. Education and Employment

Although racial minority groups made up over 22 percent of the U.S. population in 1976, they accounted for only about four percent of all scientists and engineers.[1/] Even that figure does not truly reflect the situation because the various groups differ from one another in their participation in science and engineering and one subgroup, the Asian-Americans, is overrepresented (in terms of its proportion in the total population) in engineering and all science areas except psychology and social science.

Table 1 shows that ethnic and racial minority groups, except for the Asian-Americans, are severely underrepresented in engineering and in all the sciences. Blacks earn degrees somewhat more often in psychology and social science and less often in the physical sciences and engineering. Hispanics tend to lag in all the fields about equally, though, again, there is some favoring of the less mathematically based pursuits. There are so few Native Americans who receive degrees in some fields that the proportions are very unstable (e.g., three Ph.D.'s in engineering, one in computer science, 15 M.S. degrees in biological science, etc.), but there does not appear to be any particular field to which they gravitate.

There is some indication that over the past few years the proportion of minority students in science and engineering (and in higher education in general--see the National Report series published by the Admissions Testing Program of the College Board) has been increasing. In engineering, for example, Black, Hispanic, and Native American enrollment was 5.7 percent of the freshman class in 1973 and 8.03 percent in 1977.[2/] The latter figure is still only one-half of the proportion of these groups in the total U.S. population.

TABLE 1. Minority student representation among degrees granted in Engineering and Science fields.

Proportion (%) of Degrees Awarded 1975-76

	Proportion in U. S. Population 1977	Engineering			Computer Science			Mathematics		
		BS	MS	Ph.D	BS	MS	Ph.D	BS	MS	Ph.D
Black	11.6	2.9	1.3	0.6	5.8	2.1	-	4.9	3.1	0.9
Hispanic	5.3	1.8	1.4	0.6	1.5	0.6	0.4	1.5	1.3	1.3
Native American	0.4	0.3	0.2	0.1	0.1	0.3	0.4	0.3	0.2	0.1
Asian American	1.3	2.1	3.0	4.2	2.2	2.6	1.6	1.9	2.4	2.3
Total Degrees Granted (Thousands)		45.6	16.0	2.8	5.6	2.5	0.2	15.9	3.9	0.9

	Physical Science			Biological Science		
	BS	MS	Ph.D	BS	MS	Ph.D.
Black	2.9	2.4	0.9	4.1	3.1	1.3
Hispanic	1.3	1.0	0.8	1.6	0.8	0.6
Native American	0.3	0.2	0.2	0.3	0.2	0.1
Asian American	1.5	2.6	2.5	2.2	1.9	2.5
Total Degrees Granted (Thousands)	21.2	5.4	3.4	54.2	6.6	3.4

	Psychology			Social Science		
	BS	MS	Ph.D	BS	MS	Ph.D
Black	6.3	5.2	2.4	8.5	5.4	2.6
Hispanic	2.5	2.3	1.5	2.4	1.8	1.9
Native American	0.4	0.2	0.2	0.4	0.2	0.2
Asian American	1.2	1.1	0.8	1.1	1.2	0.9
Total Degrees Granted (Thousands)	49.8	7.8	2.6	126.4	15.9	4.2

Source: Adapted from Table V-21; p. 121 Science Education Data Book, NSF, 1980.

Many economic, social, educational, and psychological reasons have been advanced to help explain why minority students choose science and engineering careers less frequently than do White/Anglo students. Whatever the causes, the minority underrepresentation in science-oriented pursuits begins early in the educational process.[3/] Blacks and Hispanics enter college at lower overall rates than Whites,[4/] and Hispanics opt for two-year institutions (where science and engineering training is less available) at a rate nearly double that for White and Black students.[5/]

Once started in college, both Black and Hispanic students withdraw at slightly higher rates than do White students at four-year institutions and at markedly higher rates at two-year institutions. Under all circumstances, the withdrawals are heavily (73 percent-88 percent) for nonacademic reasons,[6/] which suggests that economics plays a significant role.

In terms of persistence toward degrees in science and engineering, Table 1 shows that except for Asian-Americans, minority groups make up decreasing proportions of degree recipients as they progress from B.A. to M.A. to Ph.D. levels.

2. Standardized Test Scores

Results of the Scholastic Aptitude Tests (SATs) indicate large differences between majority scores and scores for the Black minority. Data recently released by the Educational Testing Service show that during the five-year period from 1972-73 to 1976-77, Black students scored 119 points lower than Whites on the verbal section, and 134 points lower than Whites on the mathematics section.[7]

Similar results are found on a variety of other standardized tests, including the NAEP mathematics and science achievement tests, with Hispanics often scoring, on the average, roughly mid-way between Blacks and Whites.

Native Americans, possibly because of their small numbers, are rarely included as an identified subgroup in educational statistics. Their opportunity to participate in science and engineering pursuits may be even more greatly hampered than with the Black and Hispanic minorities because a great many attend rural schools which have very poor resources. Moreover, it is difficult to assess the extent of many problems because the Bureau of Indian Affairs and the Office (now the Department) of Education have used different criteria to define who is a "Native American" and thus have made strikingly different estimates of the total number.

Federal action can help to narrow the gap--notably through efforts to eliminate racial discrimination, through steps taken to reduce the general disadvantage of minority populations (e.g., poverty, malnutrition), and through compensatory educational programs (such as Title I and Head Start). However, college-bound seniors planning to study the sciences generally have high SAT scores. In particular, those planning to study physical science and engineering have higher scores on the average than those planning study in any other field. Since few Blacks and not many more Hispanics have had the necessary training to score at these high levels, the problem of significantly improving minority representation in science and engineeering is large and progress is likely to be slow.

Status of Women in Science and Engineering

1. Employment

In 1976 only about nine percent of the science and engineering work force were women, with the great majority being in science rather than engineering.[8/]

Although women are still clearly underrepresented in these professions, the situation has improved substantially during the past decade. A sizable and growing fraction of the most recently trained scientists and engineers in the work force are women. Between 1974 and 1976 the number of women scientists and engineers increased at a rate nearly double that for men (15 percent vs. 8 percent). In 1978, women received 24 percent of all master's degrees granted in science and engineering fields and 19 percent of the Ph.D.'s, with the numbers heavily weighted toward the biological and social sciences. Even in the physical sciences and engineering, fields in which women are particularly underrepresented, the proportion of the bachelor's degrees earned by women has climbed rapidly since 1970.[9/]

Persistence of women in science and engineering employment is high; education is not "wasted" on women in any sense. Given this fact, and the relatively low representation of women in the science and engineering labor force despite the rapid progress that has been made, women still remain the largest pool of talent available for increasing the size and quality of the science and engineering labor force.

2. Education

At the high school level, the mean number of years of study of mathematics and the physical sciences for college-bound seniors differs somewhat by sex, with males taking more of these courses than females. In mathematics the difference is about one-third of a year, while in the physical sciences it is closer to one-half a year.[10/] The importance of this difference is difficult to judge without further information. However, better counseling and career information for girls in the elementary and secondary schools, as well as greater encouragement generally to study mathematics and science, would be useful.

One analyst writing on this subject for the current study has suggested that stronger college-entrance requirements in mathematics and science for all students would result in better preparation for women in particular, because of this existing differential in course enrollments.[11/]

At the bachelor's level, the figures show a steady increase in the proportion of women in virtually all science and engineering fields over the past decade. At the doctoral level, women made up 10.4 percent of the science and engineering work force in 1977, up from 9.3 percent in 1975 and from 8.5 percent in 1973.[12/] Their representation in the various disciplines is significantly different than at the bachelor's level.

For example, only about 13 percent of all doctorates in the mathematical sciences go to women--considerably below the 18 percent level for all science and engineering doctorates.

Status of the Physically Handicapped in Science and Engineering

Significant legislation at the national level regarding the physically handicapped has emerged in the past few years. The Vocational Rehabilitation Act of 1973 is intended to do for the handicapped what the Civil Rights Act did for minorities and Title IX did for women. The Education of All Handicapped Children Act of 1975 (P.L. 94-142) is designed to assure that handicapped children have available to them an appropriate free public education.

The major thrust of these statutes with regard to science education is to require mainstreaming of many handicapped students--that is, the accommodation of such students in regular classrooms as much as possible. This, in turn, requires changes in attitudes, correction of architectural barriers, better teacher training, and a variety of other changes on the part of individuals, institutions, professional societies, and agencies of government.

Approximately one percent of the population is severely physically handicapped: blind, deaf, or significantly orthopedically limited. While data are not available regarding the percentage of scientists and engineers who are severely handicapped, it is implausible to assume that it is anywhere near one percent of the 2.7 million persons in the science and engineering work force. Whatever the exact figure, a significant number of handicapped scientists and engineers do exist and can function very effectively. For example, in recent years over 800 disabled scientists have become known to the American Association for the Advancement of Science's (AAAS) Project on the Handicapped in Science.

Publications of the AAAS Project on the Handicapped in Science are recommended for those interested in a fuller discussion of the situation facing the handicapped in science education.

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3. National Assessment of Educational Progress. Mathematical Knowledge and Skills (1979), p. 45.

4. National Council for Educational Statistics. Withdrawal from Institutions of Higher Education, p. 31, Table IV-7. Washington, D.C.: U.S. Government Printing Office, 1977.

5. ibid.

6. ibid.

7. Chronicle of Higher Education, January 7, 1980, p. 5.

8. op. cit., Note 1, p. 234, Table 5-19.

9. op. cit., Note 1, p. 237, Table 5-22.

10. Admissions Testing Program of the College Board. National College Bound Seniors, p. 14, Table 6. Princeton, N.J.: 1979.

11. L. S. Hornig. "The Missing Scientists: Women in Science and Engineering." (NRC Paper, Appendix D-1).

12. Scientific Manpower Commission. Professional Women and Minorities, p. 55, Table G-WF-11, and p. 59 Table G-WF-17. Washington, D.C.: 1978 (Supplemented 1980).

APPENDIX D

LIST OF CONTRIBUTIONS

Papers Commissioned by The National Research Council*

Robert A. Alberty (Dean of Science, Massachusetts Institute of Technology), The Future of Doctorate Education in the Sciences and Engineering.

Examines doctoral education, shortages, retirement rates, and future needs.

Bill G. Aldridge (Executive Director, National Science Teachers Association), Letter Concerning Supply/Demand, Pay, and Status of School Teachers of Science and Mathematics.

Provides graphs for enrollments, grades 7-16, and for teacher projections, grades 7-12. Discusses shortages of secondary physics and chemistry teachers and the reasons for them.

American Physical Society (Herman Feshbach, President), The Education of Physicists.

Details policy recommendations on the education of physicists in the 1980s, noting issues such as women in physics, faculty prospects, manpower projections, and employment opportunities.

American Society for Engineering Education (Donald E. Marlowe, Executive Director), Memorandum on Engineering Education.

Analyzes the state of engineering education, noting recent problems in areas such as secondary education, undergraduate education. Discusses engineering societies' analysis and makes recommendations.

David W. Breneman (Senior Fellow, The Brookings Institution), Graduate Education in Science and Engineering: Prospects and Policy Options.

Reviews graduate education support options. Updates reports from National Board on Graduate Education, Smith-Karlesky, and fifteen university presidents. Discusses options such as expansion of graduate and postdoctoral education, retraining, and state and/or private sector support.

Harvey Brooks (Benjamin Peirce Professor of Technology and Public Policy, Harvard University), The Sputnik Syndrome Revisited.

Evaluates impacts of post-Sputnik programs designed to improve science and engineering education, focusing on effects on output of scientists and engineers, research and graduate education, curricula reforms, and future issues suggested by past efforts.

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* The opinions expressed by the authors of these papers are their own and do not necessarily reflect those of the National Research Council, its officers or its staff.

Kenneth E. Clark (University of Rochester), Societal Influences on Educational and Career Decisions of College Undergraduates.

Examines how the system affects the supply of talent in science and engineering and gives recommendations.

Derek de Solla Price (Avalon Professor of History of Science, Yale University), Science Indicators of Quantity and Quality for Fine Tuning of United States Investment in Research in Major Fields of Science and Technology.

Reviews complex data analysis and provides extensive supporting materials. Data analysis concerns cross-national flow of scientific information and the relative contributions of individual nations as measured by numbers of articles and references to articles in other documents.

Nicholas DeWitt (Professor of Economics, Indiana University), Summary Findings: The Current Status and Determinants of Science Education in Soviet Secondary Schools.

Highlights structural and societal status of science and mathematics education in the U.S.S.R. and makes relevant comparisons with U.S. where possible. Considers goals, curricula paths, transition from secondary to higher education, relative emphasis on course requirements, and teachers.

Cleveland L. Dennard (President, Atlanta University), Increasing Minority Representation in Science and Engineering.

Gives a historic view and makes recommendations.

Richard G. Folsom (Formerly President, Rensselaer Polytechnic Institute), Accreditation of Engineering Programs.

Describes accreditation, discusses issues, and makes suggestions for possible action.

Margaret S. Gordon (Institute of Industrial Relations, University of California, Berkeley), Lost Talent: The Problems of the Secondary Schools.

Reviews the need for closer coordination of labor market programs with the motivation and performance of students. Considers primary problems, evaluates the need for reform such as work-study programs and magnet schools, and notes the roles of Federal and State governments.

Lee Grodzins (Department of Physics, Massachusetts Institute of Technology), The Field Mobility of Doctoral Scientists and Engineers:
I. The Fungibility of Scientists: Intrinsic Correlations Between Fields
II. Components of Supply and Demand.

I. Evaluates the fungibility factors between science and engineering subfields and the likelihood that practitioners will be able to switch from one field to another. II. Determines the number of people who will or have switched fields because of market forces and estimates the field mobility component of supply and demand.

Kenneth R.R. Gros Louis (Dean, College of Arts and Sciences, Indiana University), Public Programming in the Sciences.

Compares National Endowment for the Humanities (NIH) and NSF approaches to public programming/education, focusing on differences between passive information transmissions and information projects which involve the potential learner in planning and execution.

Lindsey R. Harmon (Formerly Director of Research, Commission on Human Resources), Scientific/Technical Manpower for the 1980's: Field Mobility.
Examines a variety of methods for dealing with manpower shortages and the extent to which the manpower pool can adapt to changes in supply and demand. Examines previous shortage periods, relates field mobility to educational specialization and attitudes, notes trends, and makes recommendations.

Donald F. Hornig (School of Public Health, Harvard University), Reflections on Strengthening Science and Engineering Education.
Discusses means of improving science and engineering based on the author's qualitative experiences. Reviews history of government interest and examines specific cases of Office of Naval Research, NIH, NSF, and other agencies.

Lilli S. Hornig (Higher Education Resource Services, Wellesley College), The Missing Scientists: Women in Science and Engineering.
Examines the possibility of increasing the quantity and quality of the science/engineering workforce by increasing women's participation in science education, discusses various strategies to recruit and educate more women scientists and engineers, recommends policies to increase the effectiveness of science education for women.

Lloyd G. Humphreys (Acting Dean, College of Liberal Arts and Sciences, University of Illinois at Urbana-Champaign), Education in Science for the Black Minority.
Discusses racial differences in achievement and the extent of the problem. Suggests solutions will have to be in early childhood.

Lyle V. Jones (Director, L.L. Thurstone Psychometric Laboratory, University of North Carolina at Chapel Hill), Changes in Achievement Scores of Pre-College Students in Mathematics and Science: A Review of the Evidence.
Reviews evidence on changes in achievement scores. Compares mathematics and science scores to other areas, noting possible reasons for declines and potential policy implications.

Fred Landis (Dean, College of Engineering, Engineering and Applied Science, University of Wisconsin, Milwaukee), Demand Projections for Engineers Through 1987.
Outlines a methodology for projecting engineering demand through 1987 in selected industrial groups based on economic growth assumptions for the period 1977-1987.

Douglas M. Lapp (Director, Science Materials Center, Fairfax County, Virginia Public Schools), The Motivation of Students and Teachers of Secondary Science and Mathematics.
Describes student attitudes, analyzes some of the factors affecting student and teacher motivation, and compares the situation with secondary schools in the Soviet Union. Suggests strategies for improving student and teacher motivation and recommends government policies that might support such strategies.

Quentin W. Lindsey (Science and Public Policy Advisor, Office of the Governor, State of North Carolina), North Carolina School of Science and Mathematics: A Strategy for Improving Education in Science and Mathematics.

Reviews objectives and approaches used in planning the North Carolina high school of excellence for science and mathematics. Discusses survey of stakeholders, potential problems, the importance of state initiation of such efforts, means of transferring acquired knowledge to the rest of the school system, and implications for Federal policy.

Michael S. McPherson (Department of Economics, Williams College), Surplus or Shortage? The Emerging Market for Ph.D.'s in Science and Engineering.

Reviews existing demand and supply projections for Ph.D. scientists and engineers during the 1980s, policy implications, and quality concerns.

Roy Radner (Bell Laboratories), National Needs and the Declining Supply of Young Scientists.

Addresses the causes of the projected decline in the demand for, and supply of, new science and engineer Ph.D.'s in the research sector of academia, the adverse affects of such a decline, and gives a brief analysis of alternative policies and an outline of a Young Scientist program.

Philip C. Ritterbush (Program Director, Institute for Cultural Progress), Science Education for Public Awareness and Involvement: Comments on the Federal Role.

Discusses national purposes, quantity and quality of information provided outside formal educational institutions, and possible policies for achieving desired levels of public awareness and involvement.

David Z. Robinson, New Video Technology in Science and Engineering Education.

Describes techniques and what is needed for them to become effective. Suggests some government initiatives.

Lewis C. Solmon (Executive Officer, Higher Education Research Institute), Dealing with Prospective Shortages in the Science and Engineering Labor Market.

Gives evidence from the data, discusses general problems of intervention strategies, the "Young Investigator" problem for academic institutions, and planned programs for stimulating research output. Presents two proposals to enhance the working of the market, and states Council for Economic Development's recommendations for taking constraints off industry.

Julian C. Stanley (Study of Mathematically Precocious Youth, Johns Hopkins University), Helping Youths Who Reason Extremely Well Mathematically to Forge Ahead Better Educationally.

Details the Johns Hopkins Study of Mathematically Precocious Youth (SMPY) and examines obstacles to optimizing the abilities of gifted children. Reviews possible approaches to mitigate problems cited by identifying and adapting to gifted children.

Task Force on Engineering Education (National Academy of Engineering), Issues in Engineering Education: A Framework for Analysis.

Summarizes major report by the Task Force and details survey undertaken to identify major issues in engineering education. Examines current state of engineering education and details concerns and recommendations for immediate and long-term action.

Eric A. Walker (President Emeritus, Pennsylvania State University), Engineering and Engineers: Definitions and Utilization.

Reviews important engineering education issues, including diversity of profession, accreditation and licensing, sufficiency of supply, and graduate education.

Carl R. Wischmeyer (Director, Education Center, Bell Laboratories), Continuing Education in the Industrial Setting.

Reviews in detail the planning, operation, and success of Bell Laboratories continuing education program, focusing on appropriate management roles, participant selection, and curricula.

Assessments Contributed by Representatives of Other Nongovernmental Organizations

Accreditation Board for Engineering and Technology, Inc. (ABET)*

Reviews opinions of David R. Reyes-Guerra, Executive Director, on the issue of the quality of engineering education. Transmits copy of recent report on engineering education. Discusses public perception of engineering, pre-college and college factors affecting students and quality, graduate programs, and continuing education.

American Academy of Environmental Engineers (AAEE)

Provides draft report, "Position Paper of the American Academy of Environmental Engineers on the Proper Role of EPA in Water Quality Manpower Development." Report notes limitations of sole reliance on market forces.

American Association for the Advancement of Science (AAAS)*

Reviews opinions of William D. Carey, Executive Officer, on the four dimensions of national needs (excellence in research and graduate education, skill requirements of R&D-intensive industries, profiles of technology base, and elementary and secondary science/mathematics). Notes trends, system characteristics, and policy options.

American Association of Engineering Societies (AAES)

Provides data on engineering and technology and on engineering and technology enrollments. Discusses the training of support personnel for engineers. Transmits Engineering Manpower Commission. Engineering & Technology Enrollments, Fall 1979: Part I, By School; Part II, By Minorities; Part III, By Curriculum, and Engineering & Technology Enrollments: Part I, Engineering and Part II, Technology.

American Association of Physics Teachers (AAPT)*

Reviews opinions of Arnold Strassenburg, Executive Officer, focusing on quality of undergraduate and graduate education, impact of fiscal pressures, potential shortage areas (notably secondary teachers), curricula, and continuing education for professionals and the general public.

American Association of School Administrators (AASA)

Discusses (in letter from William G. Spady, Director, National Center for the Improvement of Learning) the availability of mathematics and science courses, teachers, and programs and the attractiveness of such programs to women, minorities, and other students.

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* These assessments were provided by individual office staff members of these organizations and do not necessarily reflect the views of the organizations themselves.

American Association of University Professors (AAUP)*

Transmits responses from three AAUP members: Leroy Dubek (discussing national needs, current science and engineering education problems, and potential solutions), Jay Scribner (in collaboration with two science education professors, assessing national needs, important trends, system's stresses, and policy options), and Dennis Marks (noting need for competent elementary and secondary teachers and the limits of relevant Federal policy).

American Federation of Information Processing Societies, Inc. (AFIPS)

Provides degree data on computer professionals.

American Geological Institute (AGI)*

Transmits opinions of William H. Mathews III, Director of Education, on science and engineering education in geosciences, emphasizing no serious quantity/quality problems at undergraduate or graduate level, increasing numbers of interested students because of energy and environmental concerns, impact of limited support for research, role of continuing education, and possible role of secondary schools.

American Institute of Physics (AIP)*

Transmits paper by Lewis Slack on science and engineering education to preserve national strength, as well as numerous resource materials on educating and training physicists (including AIP material from report Physics Manpower 1966 and from Employment Survey 1978).

American Physical Society (APS)

Transmits The Transition in Physics Doctoral Employment 1960-1990, Bulletin of the American Physical Society, v. 25, Number 2, February 1980 (report on the work done by the Physics Manpower Panel), Bulletin of the American Physical Society, Executive Summary of The Transition in Physics Doctoral Employment 1960-1990 by M.D. Fiske.

American Political Science Association (APSA)

Transmits "Future National Needs in Political Science Education" by Sheilah K. Mann, Director, Educational Affairs. Describes relevance of political science to science and engineering and briefly documents the state of the quantity and quality of political scientists.

American Psychological Association (APA)

Transmits memorandum detailing relation of psychology to science education, levels of psychology manpower (current and future), perceptions of science and engineering career opportunities, and need for support at all levels of educational system (especially in equipment, stability of research funds, teacher training, and modification of Federal policy).

American Vocational Association (AVA)

Transmits draft statement by Howard Lawrence and Anne McNutt, Nashville State Technical Institute, reviewing need for and existence of national education policy, current problems and trends in vocational education, needs of nontraditional students, teacher qualifications, and criteria for new national policies.

Association for Computing Machinery*

Review by Alfred Bork, University of California, Irvine, of the need for science literacy, new learning institutions, and computer science literacy as a special case. Examines unhealthy state of science and engineering education, notes potential of computer-aided instruction, and offers recommendations.

Bell Laboratories

W.O. Baker, Chairman of the Board, transmits articles, addresses and testimony before the Subcommittee on Science, Research and Technology, U.S. House of Representatives.

Brookhaven National Laboratory (BNL)*

Provides explanation and explanatory materials for Gertrude Goldhaber's proposal to the American Physical Society to improve the understanding of physics and its role in the U.S. economy and society.

Business-Higher Education Forum

Provides review of 1980 conference on Engineering Manpower Issues. Includes Scientific and Engineering Manpower, 1979, by Rockwell International, which examines ongoing surveys, analyzes projections, discusses manpower patterns and cycles, notes limitations on manpower planning, and considers policy options.

Council of Scientific Society Presidents (CSSP)

Transmits preliminary report prepared by R.D. Anderson, Chairman, observing the utility of a review by a high-level interdisciplinary panel and notes major stresses which should be evaluated (e.g., the knowledge explosion, demographics, inflationary impacts, and broadened employment bases). Offers recommendations for Federal action.

Council of Virginia Engineering Deans

Letter to President Carter discusses shortages of doctoral students and faculty and the impact on quality of education.

Committee for Economic Development (CED)*

Frank W. Schiff, Vice President and Chief Economist, provides numerous materials relevant to education for the disadvantaged and for hard-to-employ students. Includes some materials on minorities and women in science and engineering.

Education Commission of the States

Provides information on progress assessments and on attitudes toward science study.

Engineering College Council*

Transmits statement by Donald D. Glower discussing the differences between engineering and science; the shortages of doctoral students, young U.S. faculty and equipment in engineering schools; the preparation of students at the secondary level; and gives policy recommendations. Also includes a position statement, "An Initiative to Promote and Increase the United States Productivity by Integration of Interactive Computer Graphics Equipment into the Curricula of U.S. Engineering Colleges and

Universities," presented by the Deans of the Colleges of Engineering of the Big Ten Universities and Stanford University, August 9, 1978.

Federation of American Societies for Experimental Biology (FASEB)*

Reviews opinions of Robert W. Krauss, Executive Director, on educational quality, noting issues such as the need for superior scientists and engineers, deteriorating secondary curricula, university-level impediments to superior education, noncompetitive faculty salaries, the need for continuing education, space/equipment limitations, and the impact of inflation.

Institute of Electrical and Electronics Engineers, Inc. (IEEE)

Outlines draft position statement of executive committee on engineering education, detailing the current crisis, professional awareness of the crisis, faculty levels and salaries, graduate program quality, and available financial support. Offers recommendations.

Mathematical Association of America

Provides consensus opinions of Alfred B. Willcox, Executive Director, and seven consultants, focusing on mathematics issues such as the lack of a recent study of national goals, manpower shortages in the 1980s, relevant curricula integrated with other fields, faculty shortages (especially at secondary level), impact of inflation and new technologies, and need for continuing education. Provides additional comments by Dorothy L. Bernstein, President, on the need for a sound mathematical education for all scientists and engineers and the need for a group to monitor new applications of mathematics.

National Association of Biology Teachers

Transmits draft statement discussing need for an enlightened citizenry, trends affecting training and utilization of personnel, qualities of biology and science education, anticipated stresses on the educational system, science curriculum development, and private and public policy.

National Association of State Boards of Education*

Transmits letter from Wesley Apker, Executive Director, listing problems of science and engineering education and listing needs implied from the problems.

National Association of State University and Land Grant Colleges

Transmits report for Association by C.H. Wang, Oregon State University, on supply and demand of scientists and engineers in energy-related areas. Describes energy and energy manpower crisis, identifies energy-related needs in solar, fission, fusion, and synfuels energy, and offers recommendations to supply needed engineers.

National Council of Teachers of Mathematics (NCTM)

Transmits a letter from James Gates, Executive Director, listing major problems in school mathematics. Encloses the articles: "Combating the Crisis of Confidence," "An Agenda for a Decade of Action," "The Essentials of Education," developed by the National Council of Teachers, and a press release of October 19, 1978, regarding the shortage of mathematics teachers.

National Science Teachers Association

Provides analysis of enrollment trends over the past ten years, based on NCES statistics. Relates enrollments to financial support, cites 1980 study of secondary schools and faculties, and examines causes and effects of shortage of engineers.

National Parent-Teachers Association (NPTA)

Transmits letter from Virginia Sparling, President, discussing the principal national needs of science and engineering education, quality and quantity of scientific and engineering personnel, important trends, current Federal policies, stresses in the educational system, institutional mechanisms, private and public policies, and lists questions for assessing science education in schools.

Pennsylvania State University*

Letter from B.F. Howell, Jr., discusses problems related to support for graduate students, and obsolescence of equipment in educational institutions.

SRI International

A Summary Report on the Educational System of the United States and the Soviet Union: Comparative Analysis, March 1980. SRI International Strategic Studies Center, Training and Utilization of Scientific and Engineering Technical Personnel, November 1979.

Describes the history and characteristics of primary, secondary, and higher education, notes admission procedures and trends in undergraduate and graduate students, reviews current and expected employment and salary trends for scientists, engineers, and technicians, and examines mobility and continuing education issues.

Texas Deans of Engineering

Recognizes the problems of engineering colleges to maintain a high quality and quantity production of engineering graduates and makes recommendations.

Assessments Contributed by Individuals

D. Allan Bromley, "U.S. Universities and the Federal Government," and "Molecular Phenomena in Nuclei," Francis G. Slack lectures (Vanderbilt University), March 1979.

First lecture addresses relation between universities and the Federal Government, focusing on research, accountability, and identification and training of gifted students.

John C. Calhoun, Jr., "A University View on Factors Affecting Engineering Manpower Supply and Demand in the Drilling and Producing Sector of the Petroleum Industry" (1978), and "Analysis of Petroleum Engineers Engineering Manpower Survey" (1979).

Reviews output of, and demand for, petroleum engineering graduates.

Donald W. Collier (Borg-Warner Corporation)

Letter discusses the need for second career education and the stresses the educational system will experience as a result.

Samuel I. Doctors, Curriculum Development for Public Management of Innovations. The Private Sector Connection.

Assesses the demand for, and availability of, education and training in the field of science and technology management, discusses the relevance of private sector management of innovation and suggests a program for developing a curriculum for public management of innovations. Lists current training in public management of innovations.

Kenneth W. Ford (President, New Mexico Institute of Mining and Technology), letter and Statement to National Science Board Members, January 10, 1978.

Discusses younger researchers, supply and demand and alternative performers of basic research. Makes recommendations.

L.E. Grinter (Dean Emeritus, University of Florida)

Letter discusses doctoral level engineering, quality in engineering education, and suggests supporting carefully selected students.

Jill E. Heuer, "Soviet Scientific/Technical Manpower: Much More Than a Simple Numbers Game," Government Executive, April 1980.

Gerald Holton (Harvard University)

Suggests appointing a Kemeny-type commission and interpreting "science and engineering education" in the broadest way. States the need to go outside the charged agencies to define the semi-qualitative indicators.

Charles V. Kidd (George Washington University)

Discusses free market vs. planned market, supply-demand relationships, efforts to deal with specific shortages, Federal fellowships, and other issues. Provides questions relating to the adequacy of training in science and engineering in the U.S. and a reading list.

Douglas C. Neckers, On the Quality of Undergraduate Students Choosing Chemistry as a Profession 1961-1979, 1979.

Surveys the career goals and abilities of chemistry majors from 1961 to 1979, using data from individual schools and from 26 representative schools. Notes decline in ability (measured by test scores) of chemistry majors choosing chemistry careers in comparison to those chemisty majors choosing medical careers.

Gilbert Sanchez (Eastern New Mexico University)
Discusses ways of defining and delineating national needs, important trends such as science education at an early stage, counseling at an early age, and hands-on experimentation. Lists areas that should be stressed in the educational systems in order to fulfill national needs.

A. George Schillinger, Harold Kaufman, and Anthony J. Weiner (Polytechnic Institute of New York), and Howard K. Nason (Industrial Research Institute/Research Corporation). New Directions in Continuing Education: Comparative Perspectives of Decision Makers and R&D Personnel, Draft No. 2, 1980.
Reports on a study for NSF. Describes available continuing education programs and their origins, notes obstacles to effective continuing education in industry and academic institutions, reviews government's role in continuing education, and evaluates important trends affecting continuing education.

Edward Wenk, Jr. (University of Washington, Seattle, Washington), Engineering in the 80s, based on an address presented October 19, 1979, at the dedication of the G.W.C. Whiting School of Engineering, The Johns Hopkins University.
Examines social responsibilities of engineers, noting nature and trends of technology, impact of technology on society, and implications for engineers.

Dael Wolfle (University of Washington)
Gives sources and suggests that the supply of scientists and enginee will depend more on opportunities than on programs directed to supply, that institutions may need remedial aid, and that the report analyze national needs.

Gail S. Young (Case Western Reserve University)
Letter discusses potential for imminent shortage of mathematicians (manuscript attached).

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Assessments Prepared by U.S. Government Agencies

U.S. Department of Agriculture (USDA)

Transmits detailed summary of USDA Manpower Assessment Project, which focuses on current and future supplies of scientists for agriculture, job opportunities in the field, and adequacy of supply to meet demands.

Department of Defense (DOD), Office of the Deputy Undersecretary of Defense for Research and Advanced Technology.

Provides draft analysis of DOD manpower needs and problems. Provides guidance on study of science and engineering education, analyzes military sector demand, identifies impending obstacles to adequate manpower supplies (internal and external), and suggests institutional mechanisms for solving major problems.

Transmits Special Report of the U.S. Air Force Scientific Advisory Board Ad Hoc Committee on Scientific and Engineering Manpower Shortfalls Within the Air Force. Reviews relevant educational trends, demand and supply for Air Force needs, and potential short-term and long-term alternatives to improve Air Force ability to attract and retain scientists and engineers.

Describes preliminary analysis of Army manpower needs, impending problems in meeting manpower needs (e.g., relevance of education to Army employment opportunities and internal/external factors restricting Army hiring and retention of scientists and engineers), and notes institutional mechanisms for constructive actions.

Department of Energy (DOE)

Discusses the Nation's most likely major energy sources from now to the year 2000 (based on scenarios in the CONAES and NEP II reports) and provides a preliminary description of the need for engineers and scientists (by sub-field) required to design and operate these energy facilities. Summarizes the engineering and science disciplines in which the anticipated numbers of graduates (from the B.S. to the Ph.D. level) are likely to be substantially lower than the combined needs of the energy and other technologies.

National Aeronautical and Space Administration (NASA)

Analyzes NASA and NASA-related industry demands for foreseeable future for scientists and engineers. Notes declining NASA demand but intense competition for quality graduates among industries.

National Institutes of Health (NIH)

Transmits "Assessment of Future Quantitative and Qualitative Demands for Biomedical and Behavioral Scientists in Government and Private Sector Likely to Result from Programs Related to the Mission of the NIH" and Personnel Needs and Training for Biomedical and Behavioral Research, The 1978 Report of the Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel.

APPENDIX E

LIST OF SEMINARS ARRANGED BY THE NATIONAL RESEARCH COUNCIL*

Seminar I. April 24, 1980: Broad Policy Concerns
Chair: Harrison Shull, Rensselaer Polytechnic Institute

Seminar II. April 24, 1980: Public Understanding of Science and Technology
Chair: Jack Myers, University of Texas at Austin

Seminar III. April 25-26, 1980: Preparation for Studying Science and Engineering

Group A: Pre-college Science and Mathematics
Chair: William Bevan, Duke University

Group B: Introductory Undergraduate Science and Engineering
Chair: H. R. Crane, University of Michigan

Seminar IV. April 27-28, 1980: Undergraduate Programs and Their Graduates

Group A: Undergraduate Majors in Science
Chair: Lilli Hornig, Wellesley College

Group B: Undergraduate Majors in Engineering
Chair: James Mulligan, School of Engineering, University of California, Irvine

Group C: Baccalaureates in Employment and in Graduate Schools
Chair: Robert Bromberg, Vice President of Research and Engineering, TRW Systems

Seminar V. April 29-30, 1980: Graduate Programs and Their Graduates

Group A: Graduate Programs
Chair: Robert Hill, Duke University

Group B: Masters and Ph.D.'s in Employment
Chair: Albert Clogston, Bell Laboratories

Seminar VI. April 29, 1980: Utilization and Continuing Professional Education
Chair: Margaret Gordon, University of California, Berkeley

* The National Research Council has provided the National Science Foundation with notes on the discussions at each seminar for use in preparing the present review. These notes are not to be construed as NRC committee reports.

APPENDIX F

SELECTED BIBLIOGRAPHY OF PUBLISHED SOURCES

List of Sources Compiled by the National Research Council

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