Executive Summary

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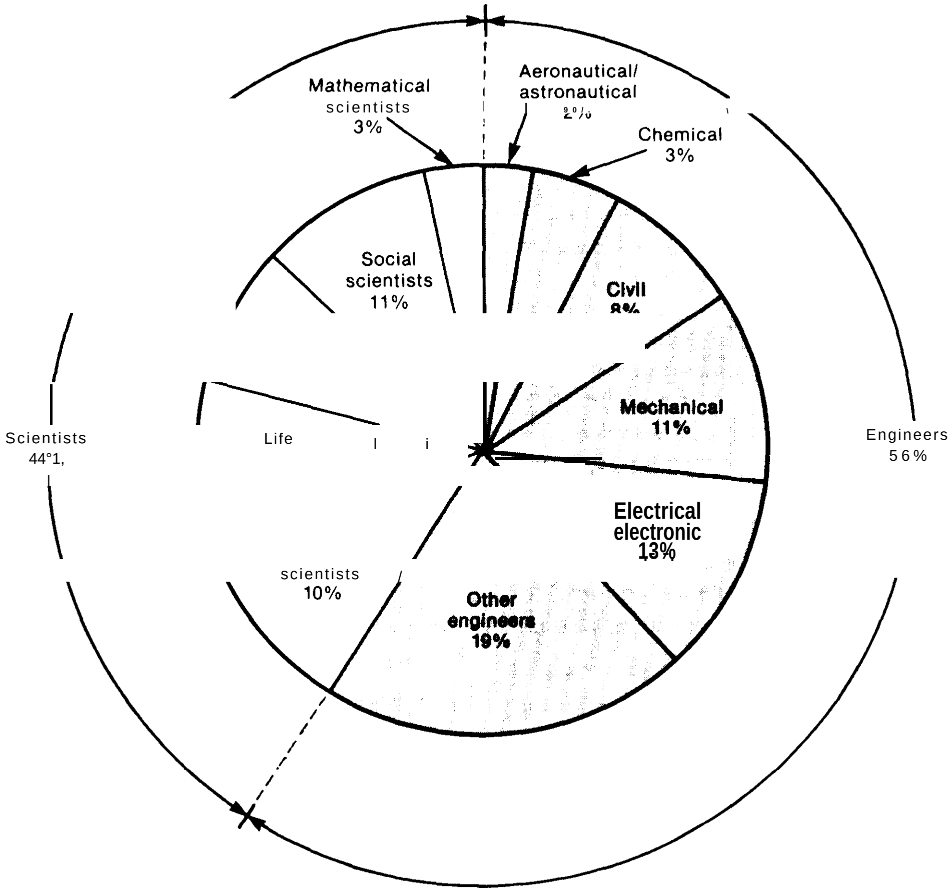
The key role of the Federal Government in educating and assuring an adequate supply of scientists and engineers has been acknowledged since the close of World War II. Scientists (including social scientists; see figure 1) and engineers represent only 3 percent of the national work force, but are considered by many to be a crucial element in the Nation's efforts to improve its economic competitiveness and national security. The Office of Technology Assessment was asked by the Task Force on Science Policy of the House Committee on Science and Technology to examine the implications of long-term demographic trends for scientific and engineering personnel policy, and to consider as well the barriers to and future trends in the participation of women and minorities in scientific and engineering *careers*.

OTA found two significant demographic trends that could affect the supply of scientists and engineers. The first is a decline in the college-age population in the next decade. The number of 18 to 24 year olds will drop from a peak of 30 million in 1982 to about 24 million in 1995, or by 22 percent. Labor market specialists estimate that the decline in 18 to *24* year olds could lead to a drop in college enrollments of *12* to 16 percent between now and 1995.

Figure I.—Population of U.S. Scientists and Engineers by Field, 1983



SOURCE National Science Foundation Science *and Technology Resources,* NSF 85-305, January 1985, pp 53-65

Second is an increase in the fraction of the 18 to 24 year old cohort that will be drawn from minority populations, including blacks, Hispanics and Asian-Americans. These groups, with the exception of Asian-Americans, have historically participated less actively in science and engineering education than whites.

Science and engineering baccalaureates have constituted 28 to 32 percent of the total number of bachelor's degrees awarded in every year since 1952 (about 300,000 have been awarded annually in science and engineering since 1972). If this historical ratio continues, the expected drop in college enrollments and changes in the student mix would lead to a decline in the number of scientists and engineers being produced by the Nation's higher education system. If, as has been argued, the Nation will require an increasing number of scientists and engineers to meet its national security, economic growth, and technological innovation requirements, this possible decline in science and engineering baccalaureates could pose a significant problem. Fortunately, OTA finds this scenario to be unconvincing.

It is entirely possible that the supply of people trained in science and engineering will not decline at all, despite the drop in the college age population. This is possible for several reasons. First, the decline in enrollment may not be as severe as predicted. The proportion of 25 to 44 year olds who attend college, and whose population cohort will not be decreasing, has increased dramatically in the past decade, especially among women, The number of foreign nationals attending U.S. colleges and universities has increased more than tenfold in the past 30 years. If increases of 25 to 44 year olds and foreign nationals continue over the next decade, they could compensate, in part, for the decline in the number of 18 to 24 year olds.

Second, there could be increases in the rate at which college students choose to major in science and engineering. Less than 7 percent of the members of a given age cohort currently receive a bachelor's degree in a science or engineering field. This is near the low point of the last decade. A slight increase in the rate of selection of science and engineering careers among college age students could more than compensate for the decline in 18 to 24 year olds projected for the 1982-95 time frame. For example, if the rate of attainment of science and engineering bachelor's degrees were to increase from the 1982 level of 6.8 percent of the 22 year old population to the 1973 level of 8.2 percent that would cause a rise in the number of degrees awarded in these fields of 20 percent, which would exceed the projected demographic decline. Projections of shortage might well serve to increase science and engineering enrollments, as the labor market responds by promising increased pay or better job opportunities.

Third, science and engineering workers can be obtained by employing a higher proportion of those obtaining the required undergraduate degrees, and drawing on the existing talent pool. Less than two-thirds of the science and engineering baccalaureates produced in recent years have actually become part of the science and engineering work force.

Finally, on the graduate level, there appears to be no direct relationship between the number of Ph.D.s in science and engineering, and the size of the graduate school age population. Between 1960 and 1970 the number of full-time graduate science and engineering students enrolled in U.S. institutions of higher education increased 150 percent, and the number of science and engineering Ph.D.s awarded increased 183 percent. At the same time the population of 22 to 34 year olds—the group which supplies the majority of graduate students—increased only 18 percent. Between 1970 and 1983, by contrast, science and engineering enrollments increased by only 36 percent and annual doctorates awarded by 1 percent, but the 22 to 34 year old population increased by more than 50 percent. **Accordingly, the reduction in the size of the college-age cohort does not inevitably lead to a reduced supply of scientists and engineers.**

There is no national market for scientists and engineers as a group. Rather, there are specific markets for graduates trained in particular disciplines, and these markets and disciplines can experience very different conditions at the same time. For example, the National Science Foundation (NSF) projected in 1982 that the demand for electrical and aeronautical engineers and for computer specialists could exceed the supply of graduates in those fields by as much as 30 percent over the next 5 years, while at the same time there would be significantly fewer openings for biologists, chemists, geologists, physicists, mathematicians, chemical, civil, and mechanical engineers than there would be trained degree-holders. **Thus, it is individual disciplines, especially those linked with high growth or defense-oriented industries, that could experience personnel problems in the future; not "science and engineering" as a whole.**

This finding is encouraging, because individual disciplines have shown great ability to grow and shrink as market conditions require. The number of engineering baccalaureates, for example, more than doubled between 1976 and *1984*, The number of bachelor's degrees in computer and informational science tripled between 1977 and 1982. At the same time, those in education, foreign languages, anthropology, history, and sociology all fell by *30* percent or more. Thus, college students appear to be highly responsive to market signals, and appear to shift their career choices dramatically toward fields that promise greater occupational rewards. **OTA concludes that career choices and market forces have a greater impact on the supply of scientists and engineers than do demographic trends.**

The possible decline in student enrollments discussed above, coupled with a low retirement rate among current faculty (most of whom were hired in the late 1960s and will not retire until the late 1990s), will lead to a very weak academic market for new Ph. D.s in the next decade. Studies carried out by a number of analysts in the late 1970s and early 1980s found that the annual demand for new junior faculty in the decade between 1985 and 1995 would fall to less than half of the levels experienced in the early 1970s. The annual academic demand for new science and engineering Ph. D.s could fall to as low as one-third the rate of hiring experienced in the 1970s during the 1985-95 time period. In the late 1990s the academic requirements for new junior faculty in general, *and* for new Ph. D. scientists and engineers in particular, should increase substantially, due to increases in both enrollments and retirements. In both cases the demand will most probably return to the levels experienced in the early 1970s and remain there through the first decade of the 21st century. The pattern of decline followed by increase will be experienced separately over the next quarter century by each of the major science and engineering fields. Although these patterns are generally acknowledged by experts in the field, considerable additional research is required to resolve uncertainties in the input assumptions to the projections—enrollments, retirements, resignations, tenure rates, and others. The consensus of experts is that **a combination of faculty and student demographics will lead to a weak academic market for new Ph. D.s over the next decade, followed by an upsurge in academic hiring between 1995 and 2010.**

In industry the demand for Ph.D. scientists and engineers has been strong for the past decade. If it should continue strong through the next decade, it could compensate for the decline in the projected academic demand. By the year 2000 industry and academia could be in stiff competition for new science and engineering Ph. D.s.

Apart from academia, however, where known demographic trends exert considerable influence, projections of supply and demand for scientists and engineers in the overall economy are fraught with uncertainty and are relatively unreliable. Such projections depend on assumptions about the future behavior of variables such as gross national product (GNP) growth, defense spending, technological change and Federal and industrial R&D expenditures, which themselves are not known with any degree of certainty. There is, moreover, no validated model that can reliably predict the career choices of undergraduates or graduate students, or their responsiveness to changes in demand in technical fields. In the absence of such a model, analysts have in the past tended to assume the continuation of existing trends, an assumption that can lead to gross inaccuracies. **Given the problems with forecasting supply and demand for scientists and engineers, predictions of shortages based on such forecasts should be treated with considerable skepticism.**

Most projections of shortages assume tacitly that demand and supply are independent, so that there can be no adjustment to supply-demand gaps. This assumption makes sense, however, only under certain *very restrictive* conditions:

1. that demand for the final product is relatively unaffected by labor costs;
2. that supply is not appreciably affected by wage changes; and
3. that the skill shortages are unique, in that workers possessing them cannot be replaced by workers from other occupations or by new technology.

If *any* of these conditions are violated, then a projected supply-demand gap will be closed by market adjustment, On the supply side, an increasing number of entry-level professionals can become trained in the shortage area, or experienced workers from neighboring specialties can move into the shortage occupation, On the demand side, employers can offer higher salaries, increase their search and recruiting efforts, rearrange jobs to utilize available skills, education and experience more efficiently, or make larger investments in training and retraining of their existing work force. **It is more important to try to understand the process of adjustment of the technical labor market to supply-demand imbalances than it is to make long-term projections.**

On the supply side, we have seen that students shift their career interests to follow signals from the marketplace. However, this response is not a short-term remedy to a supply-demand gap because it takes 4 years to train a new engineer and **6** years (from the baccalaureate) to train a new scientist in the university. In a fast-moving market, the needs of employers may change by the time entering students graduate.

Occupational mobility from related fields is the short-term response to shortages. The primary concern about occupational mobility from the employer's point of view is that it may lower the quality of work or lead to expensive retraining. From a societal point of view, however, occupational mobility appears to have served the Nation well in meeting its needs for technical personnel. The Manhattan project in World War II, the Apollo program in the 1960s, the environmental and energy programs of the 1970s and the rapid buildup of the semiconductor and computer industries all relied successfully on the importation of scientific and technical talent from related fields. Many analysts consider the mobility and adaptability of the Nation's scientific and engineering work force to be one of its greatest strengths.

Spot shortages among experienced scientists and engineers with specific areas of expertise, as have been reported in surveys of electronics and computer firms, are probably inevitable. When a new technology is developed it simply takes time before there is a pool of technically trained personnel who are experienced with the new techniques. There is no way to speed up this process more than minimally. The government could possibly help by taking a more active role in promoting the retraining of experienced engineers. Mission agency research and development programs in rapidly growing fields could possibly be modified to serve a retraining function. Apart from such assistance, however, **the government role in alleviating shortages of scientists and engineers appears quite limited.**

OTA finds that the changing college student demographics of the coming decade have several important implications for national policy to promote equality of opportunity in science and engineering. If the number of college graduates declines, it becomes especially important to utilize all potential human resources to the fullest extent possible. This means that increasing attention should be paid to those groups with historically weak participation rates in science and engineering, such as women and some minorities. The increasing fraction of college students that will be drawn from the black and Hispanic populations, which have historically participated in science and engineering education and employment at far lower rates than the white population, imply that programs aimed at increasing the participation of these two minority groups could bean especially important source of new talent. Thus, **near-term demographic trends underline the importance of promoting equality of access to scientific and engineering careers for women and disadvantaged minorities.**

Two factors stand out as crucial impediments to women's participation in science and engineering careers. The first is gender-stereotyped career expectations among younger women entering the science and engineering talent pool. These are manifested most dramatically in the major field preferences of college freshmen, where **20** percent of the men surveyed in 1984 but only 3 percent of the women, listed engineering as their field of choice. By contrast, only 4 percent of the men, but 21 percent of the women, listed education, nursing, or occupational and physical therapy as their preferred major. It appears that fields that are heavily associated with "men's work" tend to be avoided by women, just as fields that are stereotypically associated with women are avoided by men.

Girls' expectations of how they will be able to allocate their time during adulthood between participation in the labor force and work in the home also affects their career decisions. One analyst found that the more girls expect continuous labor force participation during adulthood, the more their occupational goals approximate those of their male counterparts. She also found that male single parents make occupational and labor force adaptations to parenting that look like the occupational and labor force plans of young women who expect dual family and work responsibilities. As long as women expect to assume the *major role* in housekeeping and childrearing, and to sacrifice their professional interests to those of their husband, they will be less likely than men to select occupations like science and engineering that require major educational and labor force commitments.

The second principal factor discouraging women from pursuing scientific and engineering careers is their differential treatment in the work force. Women's attrition rates from scientific and engineering careers are .50 percent higher than men's and their unemployment rates are more than double. Women's salaries are significantly lower than men's in almost all fields of science, in every employment sector and at comparable levels of experience. In academia men are far more likely than women to hold tenure-track positions, to be promoted to tenure and to achieve full professorships, even when academic age, field, and quality of graduate school attended are controlled for.

The differential treatment of women in the work force is thought by some to be the most serious violation of the principle of equality of opportunity because it affects people who have established, by virtue of obtaining an advanced degree, the right to pursue a scientific or engineering career based solely on the quality of their work. It also has a significant discouraging effect on female students in the educational pipeline, who see the future benefits of their investment in science and engineering education eroded by potential unemployment and underutilization in the work force. In sum, **gender-stereotyped career expectations and differential treatment of women scientists in the work force are the two major factors discouraging women from entering science and engineering.**

Among the minority groups that have been historically underrepresented in science and engineering, blacks, Hispanics, and American Indians receive degrees in quantitative fields at less than half the rate of whites, reflecting both lower participation in higher education and a lower rate of selection of quantitative fields. The causes of this underrepresentation are not well understood and could benefit from additional research. The quality of academic preparedness in secondary schools is cited by many experts as the greatest factor affecting these minorities' academic performance and baccalaureate attainment in college. Academic preparedness, however, appears to be related to socioeconomic factors such as parents' educational levels and social class. According to one study, the difference in the choices of quantitative majors across racial and ethnic groups are eliminated when the person is the second generation of a family to attend college. Social class, according to the same study, seems to be a proxy for a variety of family characteristics that affect school achievement, including the family's stress on achievement, language models in the home, academic guidance provided by the home, work habits and activities of the family, and the nature and quality of toys and games available to the child. They correlate very highly with children's achievement scores.

Despite the formidable socioeconomic problems responsible for the low participation rates in science and engineering among blacks, Hispanics, and American Indians, there is considerable evidence that well-designed intervention programs can assist these groups in obtaining access to science and engineering careers. To date these programs for minorities have not been rigorously and systematically evaluated to determine the ingredients of success and failure. Nor has any attempt been made to expand the coverage of the more successful programs. NSF was mandated by Congress to take a leadership role in this area, but thus far it has not done so. However, it appears safe to conclude that **the socioeconomic factors that lead to poor academic performance and an inability to remain in the science and engineering "pipeline" among blacks, Hispanics, and American Indians can be compensated for, to some degree, by well-designed intervention programs.**

Finally, OTA examined the increasing participation of foreign nationals in U.S. science and engineering education, which has raised a number of unresolved policy issues. The number of foreign nationals enrolled in American institutions of higher education has increased by a factor of 10 in the past three decades. Foreign students tend to enroll proportionately more often in engineering and medical sciences, and less in humanities and social sciences. They have assumed a very large share, **25** to **45** percent, of enrollments and doctoral degrees in graduate departments of engineering, physics, mathematics, and computer science, at the same time that the enrollment of American students in those departments declined.

There is concern that because science and engineering education is capital-intensive, and because many science and engineering graduate students are supported by Federal research assistantships, the United States is subsidizing the training of non-U.S. citizens. However, recent analysis indicates that foreign degree recipients appear to contribute more than the full cost of their education to their host institution. In addition there are foreign policy and goodwill benefits to the United States from the education of foreign citizens. It also appears that many graduate engineering departments would have had to curtail their research activities substantially without foreign graduate students.

There is disagreement as to whether individuals admitted to the United States as students who complete a graduate degree here should be allowed to remain here to accept employment. Many employers say that they cannot fill certain research and faculty positions without foreign nationals. Some professional societies, on the other hand, contend that U.S.-educated foreign engineers are taking jobs at lower pay in order to remain in this country, thus driving down salaries and reducing opportunities for U.S. engineers.

Several authors have made reference to a "growing problem" of foreign nationals on engineering faculties. They contend that the drawbacks of an increasingly foreign born faculty are limitations in their communications skills and difficulties they may have in adjusting their teaching and research styles to the expectations of American culture. Other observers note that foreign nationals may be unable to work on industry or government projects with national security or economic competitiveness implications. The validity of these assertions has yet to be documented.

The situation with respect to foreign nationals can best be summarized by saying that **although foreign nationals represent a large and growing fraction of science and engineering Ph.D.s, there is considerable disagreement over whether this constitutes a problem.**

In general, there does not appear to be convincing cause for concern that demographic trends will lead to shortages of scientists and engineers. The labor market for technical personnel has a variety of mechanisms for adjusting to potential supply-demand imbalances, and these appear to work reasonably well, without any great need for government intervention. However, the decline in the numbers of college graduates available for scientific and engineering careers in the next decade makes it increasingly important that all potential resources for the scientific and engineering work force be utilized to the fullest extent possible. For this to happen, the problems experienced by women, blacks, Hispanics, and other disadvantaged groups in entering scientific and engineering careers will have to be better understood and addressed.