Supply and Demand for Scientists and Engineers: A National Crisis in the Making

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Projections are analyzed for the future supply and demand of scientists and engineers. The demographics of the college-age population combined with estimates of the percentage of students who will pursue careers in science and engineering indicate significant shortfalls between supply and demand for the next several decades at both the baccalaureate and Ph.D. levels. If these projections are realized, the shortage of technical personnel will have a major impact on economic growth, international competitiveness, and national security. Various strategies for recruiting and retaining students in science and engineering are considered.

THE ANNUAL ADDRESS OF THE PRESIDENT OF THE AAAS provides an occasion to celebrate the past accomplishments of American science and engineering and to assess our prospects for the future. It is appropriate, therefore, to recognize that we are just one decade away from a new century and a new millennium. Although it is tempting to try to anticipate what lies ahead, looking forward is always more hazardous than looking back. A new decade, a new century, or even a new millennium is not necessarily a new point of departure. Therefore, I will not attempt to assess the discoveries that await us, or try to gauge the political and economic environment for science and technology (S&T) in, for example, the year 2020. But I am certain that in that year, science and engineering will be even more important to our national welfare than they are today. The historical record convinces me that the decisions we make about financial and human investments in science and engineering during the 1990s will be critical to the nation's vitality well into the 21st century.

This is also an appropriate time to ask whether there are lessons from the past that can guide us in making some of those decisions. One such lesson is the value of looking ahead to assess opportunities and then attempting to shape the future in light of those assessments. Just 50 years ago, a handful of farsighted individuals acted on their conviction that S&T held the key to success in a military conflict that would shortly involve the United States. On 15 June 1940, a few days before the fall of France, President Roosevelt accepted a proposal from Vannevar Bush, then president of the Carnegie Institution of Washington, to establish a National Defense Research Committee that would mobilize American science for war. Few recognized at the time that Bush's initiative would lead to a new relation between science and government—a relation that would make possible the remarkable development of American science in the years after World War II.

Establishing the postwar science-government contract that allowed the use of public funds for basic research in universities and for the education of young scientists was not a simple matter. It required considerable political negotiation between leaders of the scientific community and members of the government (*1*).

Vannevar Bush's 1945 report to the President, *Science—The Endless Frontier*, argued cogently for the legitimacy of federal support for basic research and science education (*2*). The report's principal recommendation was the creation of a new agency—the National Research Foundation, later called the National Science Foundation (NSF)—to provide that support. The budget estimated as necessary for that agency to discharge its mission was $18.5 million in the first year and $82.5 million by the fifth year (*3*).

Congressional appropriations for NSF in its first fiscal year, 1952, were $15 million; by 1958, they were $41.6 million, about half of what *Science—The Endless Frontier* had recommended. A year later, after Sputnik, NSF's appropriations more than tripled to $137.3 million.

In 1947, the President's Scientific Advisory Board, chaired by John Steelman, issued a more comprehensive report dealing with the entire national research and development (R&D) effort (*4*). National R&D expenditures in 1947 were estimated at $1.1 billion; the Steelman report recommended that they be doubled over the next 10 years. By 1957, the Korean War had intervened and federal expenditures alone had risen to $3.9 billion. The Steelman report also recommended that basic research expenditures, estimated at $100 million in 1947, should be quadrupled by 1957. But by 1957, federal investments in basic research had risen to only $262 million. Two years later, after the shock of Sputnik, funding finally reached and exceeded the recommendation made by the Steelman report.

Both the Bush and Steelman reports recognized the need to expand the human resource base for science and engineering. *Science—The Endless Frontier* estimated that as many as 150,000 baccalaureate degrees in science had been lost as a result of World War II and that the cumulative shortfall of Ph.D.'s in science between 1941 and 1955 would be 16,000. It recommended that 300 graduate fellowships be awarded each year to help reduce that deficit.

The Steelman report bluntly stated that, "under present conditions, the ceiling on R&D activities is fixed by the availability of

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trained personnel, rather than by the amounts of money available" (*4*, p. 22). In 1947, the annual production of Ph.D.'s in science was approximately 1600; the Steelman report recommended that the rate should be increased to 5500 by 1957. But by 1960, fewer than 5000 Ph.D.'s were being produced annually. Within 5 years the post-Sputnik surge finally accelerated Ph.D. production in science above the Steelman recommendation. A national crisis, in the guise of Sputnik, was required to fulfill the financial and human resource investments that the Steelman report recommended in the aftermath of World War II.

I have recalled these post–World War II attempts to gauge the future resource requirements for science and engineering not so much to demonstrate the hazards of making predictions about the future, but to remind us that the growth of R&D resources was uneven, sometimes uncertain, and often dependent on unpredictable events. The Korean War led to an accelerated growth in R&D expenditures in the early 1950s, and Sputnik was needed to provide the impetus for growth in the 1960s, even though cogent arguments for increased support had been advanced many years earlier.

Although we now regard the post–World War II years as the starting point for the flowering of American science, it is useful to recall that both the financial and human resource bases had started to expand before that period. Between 1930 and 1940, in the midst of the Great Depression, national R&D investments actually doubled from $166 million to $345 million.

Reliable data on the production of scientists and engineers before World War II are not available, but the number of baccalaureate degrees conferred by American colleges and universities had been rising since the turn of the century (Fig. 1). Approximately 30,000 such degrees were conferred in 1900. By 1920 that number reached 50,000 and in the ensuing decade doubled to 100,000. In 1950, on the eve of the Korean War, U.S. colleges and universities awarded almost 500,000 baccalaureate degrees; by 1970 that number was approaching its current level of approximately 1 million.

There have been three notable surges in baccalaureate degree conferrals since the turn of the century and, by implication, in the production of scientists and engineers. The first two occurred after World Wars I and II and can be attributed to the influx of returning veterans. Coincidentally, perceived opportunities in science and engineering also increased during those periods. During the 1920s, industrial and government research laboratories expanded rapidly. In the aftermath of World War II, increasing federal investments helped create new employment opportunities for scientists and engineers. The third surge in college enrollments began in the 1960s, fueled by the onset of the baby-boom generation. During that period, too, the post-Sputnik national commitment to S&T was still evident, and opportunities in science and engineering seemed to be bright.

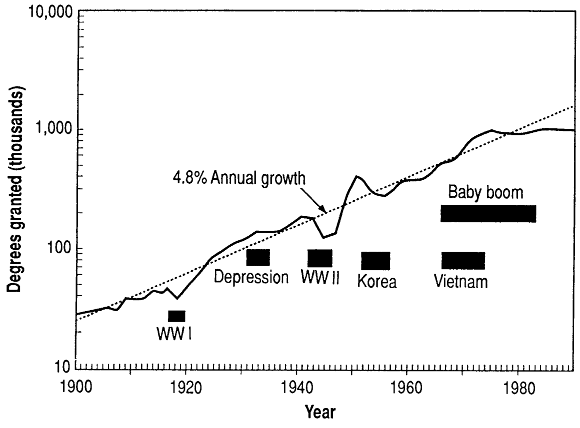

Fig. 1. Growth of U.S. baccalaureate and first professional degrees from 1900 to 1988. The dotted line shows a 4.8% annual growth rate. The baby boom bar identifies the group at 22 years of age. [Source: National Science Foundation]

A fortuitous coincidence between an available college-age population and an expanding financial base for S&T combined to fuel the three major surges in college enrollments—and, in turn, the production of scientists and engineers—during this century. Today, the need for financial and human resources adequate to meet our many domestic and global challenges is self-evident. Yet, expanding either resource base will be more difficult than in the past. Many claimants compete with science for a larger share of the federal budget, and the pool of young talent from which future scientists and engineers will be drawn continues to shrink. The most serious problem we face today is maintaining excellence and global leadership in an era of limited resources.

Constraints on Financial and Human Resources

In February 1986, the Report of the White House Science Council's Panel on the Health of U.S. Colleges and Universities (the so-called Packard-Bromley report) recommended that NSF's budget be doubled over the next 5 years to maintain the vitality of the university-based research system (*5*). Subsequent budget proposals have attempted to address that recommendation. But in each year since 1986, funds appropriated to NSF by Congress have been substantially less than the Administration's requests. For example, a year ago the Bush Administration requested $2.149 billion for NSF for fiscal year 1990, an increase of almost 12% over the 1989 level of $1.923 billion. At the end of October, the Senate and House forwarded an appropriations bill to the president with $2.072 billion for NSF—$190 million more than for fiscal year 1989. However, since the total federal budget appropriated by Congress exceeded the Gramm-Rudman-Hollings ceiling, across-the-board reductions automatically went into effect, reducing NSF's budget by an additional $28 million.

Congress' failure to appropriate NSF budget increases proposed by Bush, and earlier by Reagan, reflected no lack of awareness of the importance of research as an investment in the nation's future. The failure resulted from the Congress' need to balance a bewildering array of competing demands in the face of a bipartisan commitment to contain the budget deficit.

Although federal support for research has not increased as rapidly as we had hoped, scientific opportunities have proliferated so fast that most of them could not have been funded even if NSF's budget had doubled. Some of those opportunities require support for small to mid-sized projects; others, such as the Superconducting Super Collider and the Human Genome Project, qualify as megaprojects involving enormous financial commitments. Edward David, science adviser to President Nixon, has characterized the collision between scientific opportunities and constrained financial resources as a "crisis of purpose" for the science and engineering communities and the federal agencies that support their research (*6*). Frank Press, science adviser to President Carter, has referred to it as the "dilemma of the golden age of science" (*6*, p. 3).

Press has called on the scientific community to establish broad criteria to assist federal funding agencies in setting priorities for research support. He has challenged us to set aside parochial concerns about whether or not our favorite projects are funded in the interest of maintaining the long-term productivity of U.S. science during an era of limited resources.

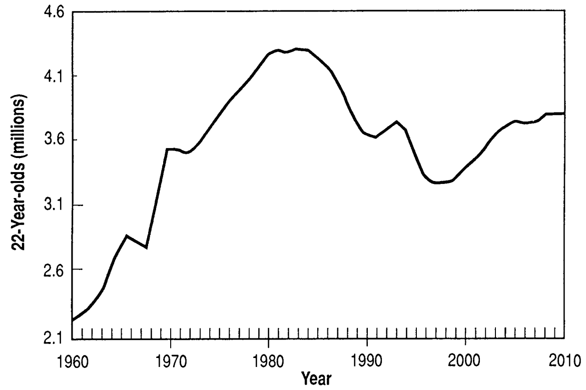

Fig. 2. Millions of 22-year-olds in the U.S. population. [Source: Bureau of Census, 1980 census]

No doubt many of us have thought about ways to escape from the dilemma posed by Press, for example, by convincing a hesitant Congress to effect significant reallocations within the total federal budget in favor of S&T. Although some adjustments are possible, the prospects for budgets large enough to address even the most promising scientific opportunities are virtually nonexistent.

In addition to financial constraints, we may also have to learn to live with severe shortfalls between the supply and demand for scientists and engineers. Prudent assumptions, based on demographic data and historic trends, indicate that there may be a cumulative shortfall of several hundred thousand scientists and engineers at the baccalaureate level by the turn of the century. That shortfall could translate into an annual supply-demand gap of several thousand scientists and engineers at the Ph.D. level, with the shortage persisting well into the 21st century.

Serious shortfalls are also projected for Ph.D.'s in the humanities and social sciences (7). Projections for those fields are based on different assumptions and do not involve demand for Ph.D.'s in the nonacademic sector—a demand that is difficult to estimate in the humanities and social sciences. In this article I shall focus mainly on the natural sciences and engineering.

The models used to project supply and demand for scientists and engineers have been subject to criticism. But most of the dispute turns on quantitative details rather than the fundamental conclusion; namely, that unless corrective actions are taken immediately, universities, industry, and government will begin to experience shortages of scientists and engineers in the next 4 to 6 years, with shortages becoming significant during the early years of the next century.

The effects of constraints on human resources could be even more severe than constraints on financial resources. Moreover, alleviating those constraints will require more than simply convincing Congress to reassess budget priorities. It will require us to convince larger numbers of young Americans that the rewards of a career in science or engineering are worth the time and effort entailed. This task will necessitate a reexamination of the values that attracted us to science in the first place and a recommitment to the proposition that research and teaching prosper best in an environment in which they are closely linked to each other.

Projections at the Baccalaureate Level

Let us consider the assumptions and models that have been used to make projections about personnel shortages (*8*). Two factors indicate that the supply of scientists and engineers at the baccalaureate level will almost certainly decline over the coming decade. First, the size of the college-age population will continue to decline until 1996 or 1997; second, it is unlikely that the percentage of college students who are awarded baccalaureate degrees in science and engineering will increase fast enough to compensate for that decline.

Changes in the size of the 22-year-old cohort in the United States between 1960 and 2010 are shown in Fig. 2. That number peaked at about 4.3 million in 1981, will decline to about 3.2 million by 1996, and then will begin to rise again. For the first few years after 1981, the decreasing size of the college-age population was offset by an increase in the percentage of individuals attending college, so that a decline in enrollment was not experienced. But a decline has now become evident (Fig. 3). One consequence of a continuing decline in college enrollments is likely to be a slowdown in demand for new faculty during the next several years.

Because of the continuing decline in the college-age population, the proportion of students receiving bachelor's degrees in science and engineering would have to increase dramatically just to maintain the current annual supply. Can such an increase be accomplished? The historical data are not encouraging. Between 1960 and 1980, the fraction of 22-year-olds receiving baccalaureate degrees in the natural sciences and engineering (including computer science) combined hovered at about 4%. In the 1980s the rate began to rise and reached 5.3% in 1986 (Fig. 4). Recent data indicate that the conferral rate in 1990 will be 4.5%, at best (*9*). That rate would have to increase to more than 6% by the turn of the century to maintain the current supply of scientists and engineers.

If instead, the conferral rates during the next 10 years remain at their average level for the 1980s, Bowen and Sosa's analysis (7) projects an annual decline of 1200 baccalaureate degrees per year in the mathematical, physical, and biological sciences between 1987 and 1997, after which the numbers would begin to increase gradually and reach 1987 levels by the year 2002. Such projections translate into an annual decline of almost 3000 baccalaureates per year in the natural sciences and engineering.

New baccalaureate-level scientists and engineers confront a variety of career options. While some of them go directly into science and engineering-related employment, others enter positions not related to their college majors. Some enroll in professional schools of medicine, law, or business administration. Only about 5% obtain a Ph.D. in science or engineering.

Because of these numerous career options, demand projections at the baccalaureate level have not been attempted. It is customary, instead, to reference the "decline" that would occur as the demo-

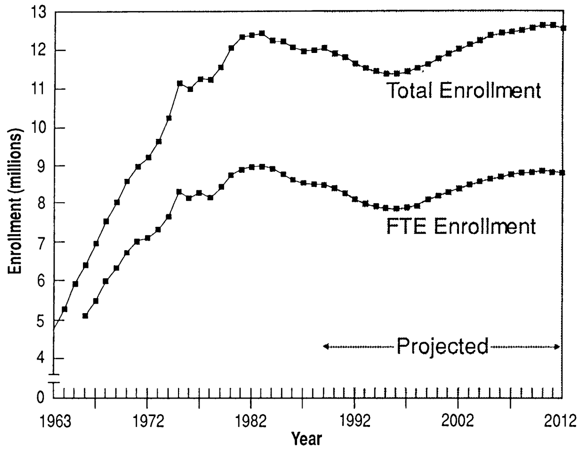

Fig. 3. College enrollment trends and projections from 1963 to 2012. Separate curves are presented for total enrollment (full-time plus part-time students) and full-time equivalent (FTE) enrollment. [Reprinted from (7) with permission, © 1989, Princeton University Press]

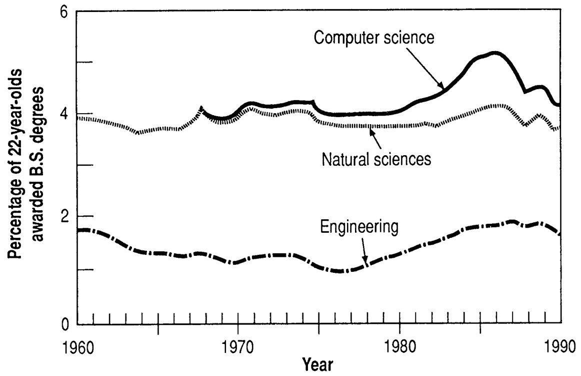

Fig. 4. Percentage of 22-year-olds awarded baccalaureate degrees in the natural sciences, computer science, and engineering. The three curves are cumulative; that is, each curve is the sum of all curves beneath it. [Source: National Science Foundation]

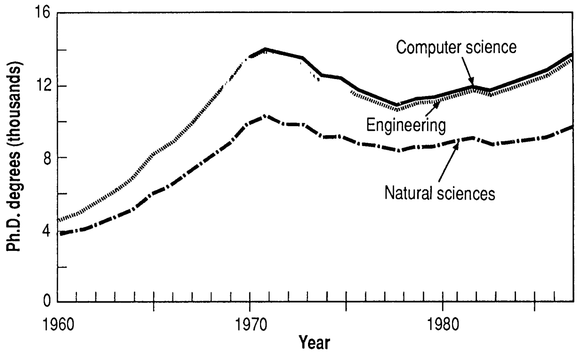

Fig. 5. Number of Ph.D. degrees in the natural sciences, computer science, and engineering from 1960 to 1987. The three curves are cumulative; that is, each is the sum of all curves beneath it. In 1987 production rates returned to the peak rate of 1971. [Source: National Science Foundation]

graphics changed, given that all other variables remain fixed at their values in a baseline year. Bowen and Sosa's projections yield a cumulative decline of nearly 70,000 baccalaureate recipients in the mathematical, physical, and biological sciences between 1987 and 1997 and more than 100,000 by the turn of the century (*7*). NSF projections, based on somewhat less conservative assumptions, project a decline of almost 400,000 in the natural sciences and engineering by the turn of the century (*9*).

It is worth noting that the employment rate for scientists and engineers is increasing faster than total U.S. employment, accounting for 3.6% of the labor force in 1986 compared with 2.4% in 1976. Thus, it is reasonable to assume an intensified competition for the scientists and engineers produced during the coming decade. Opportunities for those graduates will be excellent, a fact that needs to be emphasized to young people who are now making career choices.

Demand and Supply of Ph.D.'s

Much of the concern about constraints on human resources in science and engineering focuses on the ability of graduate schools to attract enough baccalaureate recipients to produce the Ph.D.'s required to meet future needs. Total Ph.D. production in science and engineering increased rapidly after 1960, peaked in 1972, and thereafter declined until the late 1970s; it then increased during the early 1980s (Fig. 5). Much of the recent recovery has been due to non–U.S. citizens, who accounted for 27% of all science and engineering graduate students during 1987. It is instructive to examine enrollment data by field. In 1972, U.S. institutions awarded more than 1000 Ph.D.'s in mathematics; in 1987, they awarded about 750, and only about 350 to U.S.–born students (Fig. 6). Approximately 1600 Ph.D.'s were awarded in physics and astronomy in 1972, as opposed to 1200 in 1987; two-thirds of the 1987 recipients were U.S.–born. In the biological sciences, the number of Ph.D.'s granted rose from 3500 in 1972 to 3900 in 1987, with U.S.–born recipients accounting for 3100 in the latter year.

What do these trends portend for the future? As noted earlier, somewhat less than 5% of the 22-year-old population obtains baccalaureate degrees in the natural sciences and engineering. Furthermore, of that pool 5% go on to earn Ph.D.'s in those fields. If these two 5% values are fixed, then the production of Ph.D.'s should rise and fall with the demographics of the college-age population. (The term "5 by 5 rule" is a useful mnemonic to describe this calculation.) An NSF study (*9*) has made such an analysis with the added assumption that the number of foreign students receiving Ph.D.'s in the future will remain at the present level of approximately 4500. The NSF study predicts that the number of new Ph.D.'s will rise from about 14,450 in 1988 to a peak level of 15,600 in 1993; that number is then projected to decline to about 13,000 in 2003, subsequently recovering to approximately 14,200 by 2010.

In order to transform such numbers into a supply of Ph.D.'s for the U.S. labor force, we must make an assumption about the employment of foreign students after they finish the doctorate. On average, across all fields of science and engineering, about half of the foreign-born Ph.D.'s currently enter the U.S. labor force. This 50% value is used to determine the projected supply of Ph.D.'s (Fig. 7). In judging these projections, it is worth noting that the two 5% values are optimistic given the historical record, and the 50% value for foreign-born Ph.D.'s may prove too high in the future as other nations become better able to attract their citizens back home after study abroad.

Will the Ph.D. supply be adequate to meet the demand? To answer this question, one can turn to the previously cited NSF study (*9*). In 1988 the country employed 12,189 new Ph.D. scientists and engineers—5563 in colleges and universities, 5068 in industry, and

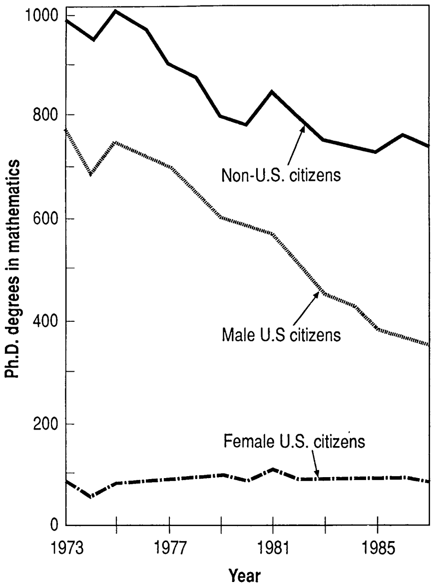

Fig. 6. Number of Ph.D. degrees in mathematics from 1973 to 1987. Curves are cumulative; that is, each curve is the sum of all curves beneath it. For example, in 1987, Ph.D.'s in mathematics were awarded to about 85 female U.S. citizens, about 265 male U.S. citizens, and about 400 non–U.S. citizens. [Source: National Science Foundation]

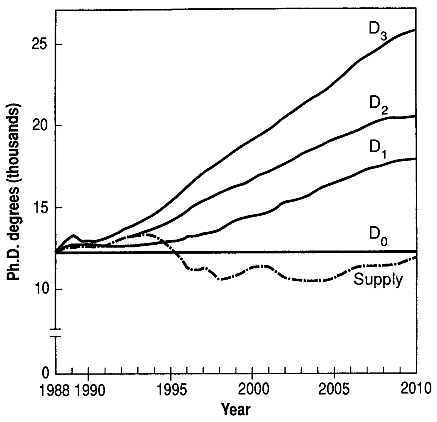

Fig. 7. Supply and demand projected to the year 2010 for Ph.D.'s in the natural sciences and engineering. Four different demand scenarios are indicated by the D_0, D_1, D_2, and D_3 curves.

the remainder in federal, state, and local governments. Slightly more than 40% of these new Ph.D.'s were replacements hired to fill existing positions created by deaths and retirements; the remainder filled new positions created as a result of expanding programs in academia, industry, and government (Table 1).

If the projected demand for new Ph.D.'s in science and engineering were to remain constant at the 1988 level, there would be more than enough new Ph.D.'s until about 1995. Thereafter, a slowly increasing shortfall between demand and supply would develop that would reach a maximum of about 1500 in the year 2003 and would virtually disappear by 2010. This demand scenario is labeled D_0 in Fig. 7.

But the constant D_0 scenario is highly unlikely for at least three reasons. First, yearly replacements due to retirements and deaths are expected to increase over the next two decades. Second, college and university enrollments are almost certain to increase in the late 1990s with the expanding college-age population, necessitating an increase in the number of faculty hired. Third, if federal and private investments in R&D continue to grow at even moderate rates, the number of new Ph.D.'s required by industry will be well above the 1988 level. These three factors generate three additional demand scenarios labeled D_1, D_2, and D_3.

Let us consider first the number of new Ph.D.'s required to fill existing positions as they are vacated because of retirements and deaths. That replacement demand was 5080 in 1988 for the academic, industrial, and government sectors combined (Table 1). Because of the age distribution of the Ph.D. work force, the replacement demand is anticipated to increase steadily over the next two decades and reach about 11,000 in the year 2010. This effect will be particularly evident in academia: most of the faculty hired during the boom period of the 1960s are still in place, but they will begin to retire in large numbers starting in the late 1990s (*7*).

The expected number of replacements is well documented, and there is little disagreement among experts about these numbers. Adding an increasing number of replacements to the D_0 scenario yields the D_1 curve (Fig. 7). This projection suggests that the shortage of Ph.D.'s will become evident in about 6 years.

In the short term, pressures created by an increasing demand for new Ph.D.'s in the nonacademic sectors are likely to be offset somewhat by a decline in the number of new faculty required to teach a decreasing number of college students. The analysis by Bowen and Sosa (*7*) indicates that all academic fields (sciences, humanities, and the arts) are likely to experience an excess supply of new Ph.D.'s until the mid-1990s, after which time the situation will rapidly reverse itself with demand outstripping supply well into the next century. That rapid reversal will occur because large numbers of faculty will be retiring just as college enrollments begin to increase once again (*10*).

As colleges and universities scramble to fill positions created by faculty retirements, they will be faced suddenly with rapidly increasing enrollments linked to the demographics of the college-age population. Assuming that the current student/faculty ratio is maintained in future years, there will be an additional demand for new Ph.D.'s to fill the expanding faculties. In 1988, the number of new positions created in colleges and universities was 2667 (Table 1); that number will fluctuate for the next several years and then grow steadily to about 5250 by the year 2010. If this increased demand is added to the D_1 scenario, the result is the D_2 curve (Fig. 7). This curve might be damped somewhat by increasing the current student/faculty ratio or by adopting policies that reduce the percentage of high school graduates going on to college, but those changes would bring a corresponding reduction in both the quality and availability of higher education.

The D_0 scenario is based on the assumption that the nonacademic sector (business, industry, and government) will add 4442 new Ph.D.-level positions to the labor force on an annual basis—in addition to replacements (Table 1). The NSF study (*9*) indicates that this growth forecast is too conservative, given historic correlations between R&D investment and the need for new Ph.D.'s. It argues that the base number should grow at an annual rate of 4% in order to maintain economic growth and international competitiveness. Given a 4% growth rate, the 1988 level of 4442 new Ph.D.-level positions would increase to about 9600 by the year 2010. Adding these positions to the D_2 demand curve generates the curve labeled D_3 (Fig. 7).

These four demand scenarios are summarized in Fig. 8. Supply and demand estimates averaged over the 16-year period from 1995 to 2010 are presented, along with the average annual shortfall. Shortfalls range from 950 for the D_0 case to 9600 for the D_3 case. Such annual shortfalls yield cumulative shortfalls over the 16-year period that range from 15,200 for D_0 to 153,600 for D_3.

My own judgment is that the D_3 projection should be given the most serious consideration (*11*). It does not represent an extreme case; it requires simply that the current student/faculty ratio be maintained in future years and that there be about an annual 4% growth rate for the number of new Ph.D.'s hired by business, industry, and government. These are minimal requirements if we believe that education and research are critical for economic growth,

Table 1. Categorized breakdown of the demand for Ph.D.'s in 1988 (*9*).

Organization	Replacement positions	New positions
Universities and colleges	2896	2667
Industry and business	1422	3646
Government	762	796
Total	5080	7109

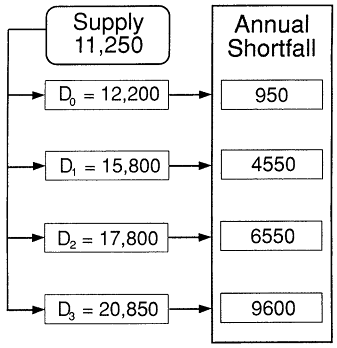

Fig. 8. The annual supply and demand for new Ph.D.'s in the natural sciences and engineering averaged over the 16-year period from 1995 to 2010.

international competitiveness, advances in health care, and national security. The D_0 case is completely unrealistic, unless we are prepared for a dramatic deterioration in the nation's education and research enterprises.

Market mechanisms will no doubt reduce projected shortfalls between supply and demand, but they will be slow in coming and expensive. As competition for a dwindling supply of new Ph.D.'s intensifies, the percentage of baccalaureate recipients who pursue Ph.D.'s in anticipation of improved employment opportunities is almost certain to increase. But that positive market signal will not be transmitted for several years. Until then, a declining demand for faculty is likely to transmit a negative signal to new baccalaureates about the rewards of graduate study. In any event, market mechanisms alone are not likely to yield appreciable additional Ph.D.'s before well into the next century. Prudence suggests, therefore, that we pursue intervention strategies to increase the future supply of Ph.D.'s by increasing the number of college students who complete baccalaureate degrees in science and engineering, and increasing the number of baccalaureate recipients who go on to obtain Ph.D.'s.

Recruitment and Retention Strategies

Are there enough qualified students to increase the production of scientists and engineers without compromising quality? Statistics collected by the Department of Education suggest that there are. These data are based on surveys that track students in the high-school classes of 1972, 1980, and 1982 beginning with their freshmen year in college (*9*). The results indicate that a large fraction of interested and qualified students are "lost" to science and engineering between their freshman and senior years in college. For the high school class of 1980:

- Only 46% of those freshmen who declared their intention to major in science or engineering eventually received baccalaureate degrees in those fields.
- Of the freshmen who switched out of science and engineering, only 31% did so because they found the course work too difficult; 43% found other fields more interesting; and 26% believed they would have better job prospects elsewhere.
- The loss of declared science and engineering students between the freshman and senior year is greater for women than for men and is greatest for underrepresented minorities.

Information about qualified students (B+ or better) who are lost to science and engineering before the freshman year in college may be even more significant for devising effective retention strategies:

- Only 58% of qualified high school seniors enrolled in 4-year colleges; 21% enrolled in 2-year or vocational colleges; and 21% did not enroll in any college at all.
- Of the 21% who did not enroll in any type of college program, fully one-fourth had taken ten or more semesters of mathematics and science in high school.

The latter group of students (with both high grades and ten semesters of science who failed to enroll in college) was about 25% of the size of the group of all students entering college with declared majors in science and engineering. The projected shortfall of the next two decades could be largely avoided if such students went on to college in science and engineering, even allowing for subsequent attrition.

These data suggest that several strategies could increase the number of baccalaureate degrees in science and engineering. Some of these strategies would be relatively straightforward. For example, targeted financial assistance could increase the likelihood that qualified high school students would enroll in 4-year colleges. Likewise, effective counseling in addition to financial assistance could help ensure that greater numbers of qualified students in 2-year colleges would have an opportunity to pursue science and engineering majors in 4-year colleges.

Retention strategies should be aimed at reducing the number of students who drop out of college, or who change from science and engineering majors to other fields. With respect to the latter, the sciences have the highest defection rates of any undergraduate major and also the lowest rates of recruitment from other fields (*12*). Anecdotes abound about science faculty who take pride in the number of students who drop their courses; they apparently equate student dropouts with rigorous instruction. Such attitudes toward teaching need to be reassessed; they are especially troubling given that the sciences attract a disproportionate number of academically superior college freshmen.

Fellowships for Graduate Education

Strategies for retaining greater numbers of students in science and engineering through high school and college need to be explored. However, even if effective programs could be put in place immediately, such programs would not generate substantial increases in science and engineering Ph.D.'s for at least a decade. Consequently, we need to ask whether more of the current baccalaureate recipients can be recruited to graduate work.

Statistics on the high school class of 1972 suggest that 20% of the men receiving baccalaureate degrees in science and engineering and 9.4% of the women eventually went on to earn some type of advanced degree. But the number actually earning Ph.D.'s in science and engineering was only 5.5% for men and 3% for women (*9*). Many of the science and engineering baccalaureates who pursued advanced degrees in other disciplines or in professional schools decided that there were inadequate opportunities in science and engineering. Among baccalaureate recipients entering the labor market directly from college, many seem to have decided that the time and financial sacrifice required for a Ph.D. were not worth the anticipated returns.

Better information about the impending shortage of scientists and engineers might convince more baccalaureate recipients to pursue the Ph.D. This information coupled with substantial increases in financial support for graduate work could be even more effective. During the period from 1969 to 1989 the number of federally funded graduate fellowships and traineeships decreased from about 60,000 to less than 14,000. Although research assistantships increased from 20,000 to about 35,000 in the same period, this gain did not approximate the decline in fellowships and traineeships (Fig. 9).

The exact mix of fellowships, traineeships, and research assistant-

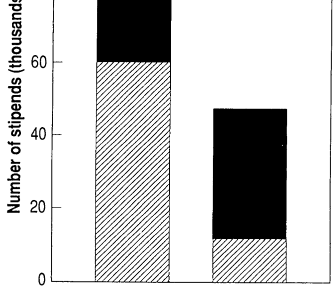

Fig. 9. Federally supported student stipends at the doctoral level. The solid section of the bar shows research assistantships, and the diagonal line section shows fellowships and traineeships. [Source: National Science Foundation]

ships that should be proposed to deal with the impending shortage of Ph.D.'s needs careful study. Any such proposal for federal support should have the following features: (i) be sufficiently flexible so that it can be modulated as updated information becomes available about supply and demand; (ii) have a mechanism to ensure that awards are targeted toward fields with the most serious shortfalls; and (iii) have special incentives for underrepresented minorities and women. A group such as the National Science Board should examine various funding options and mixes of fellowships, traineeships, and research assistantships and then make proposals.

Fellowship programs (which award support directly to students) and traineeship programs (which award funds to university departments, who then select the students to be supported) can allocate resources competitively on the basis of equally rigorous judgments of quality; the difference is whether students or departments are the unit of competition. One advantage of traineeship programs is that judgments in such competitions generally result in broader geographic distributions than do the choices of students in portable fellowship programs; such an outcome can make traineeships more attractive to Congress.

A comprehensive program for the production of more Ph.D.'s should be initiated immediately. Even with the scientific community united behind the need for such a program, it would probably take several years to formulate a broad-based plan, to convince Congress of the need, and to secure the required funding. In the meantime, a first step should be taken now—in anticipation of a more comprehensive program. What I have in mind is immediately establishing a National Program for Graduate Study similar to the National Defense Education Act (NDEA) program created after Sputnik. (Although it was called the NDEA Title IV Fellowship Program, it was in fact a traineeship program.) I described such a program to the Regents of the University of California (*13*). It called for 4-year traineeships funded at the level of $25,000 per year (a $16,000 stipend and tuition waiver to the student, plus $9,000 to the university in lieu of tuition and fees). To begin to deal with the Ph.D. shortfall, at least 3,000 new traineeships per year would be needed. At steady state there would be 12,000 traineeships in any given year at an annual cost of $300 million.

This effort alone would be insufficient for coping with the impending shortage of Ph.D.'s and would need to be supplemented with additional fellowships and research assistantships (*14*). However, as was the case with the NDEA program after Sputnik, this program would draw national attention to the fact that a serious problem exists. With a concerted effort, it could be sold to key members of the Administration and Congress during the coming months and be part of the budget package sent to Congress in January 1991.

Women and Minorities in Science and Engineering

To be effective, strategies aimed at increasing conferral rates at the baccalaureate and doctoral levels should place special emphasis on population groups for which significant increases can be anticipated. Women are the most obvious of these groups. There has been a slow but steady increase in science and engineering baccalaureate conferral rates for women over the past 30 years, from less than 1% of 22-year-old females in 1959 to 2.5% in 1986. The increase has offset a slow, parallel decline in the conferral rate for males.

In recent years, however, efforts to advance participation of women in science have stalled. The number of science and engineering doctorates awarded to women increased from the late 1950s into the early 1980s but has not increased substantially for the past several years (Fig. 10). An Office of Technology Assessment report concluded that the principal reason for the slowdown in women's interest in science and engineering careers is that women continue to experience higher unemployment, lower pay, and fewer promotion opportunities than their male counterparts (*15*). Special efforts must be made to retain women at the baccalaureate and doctoral levels and to ensure that their talents and training are more fully rewarded (*16*).

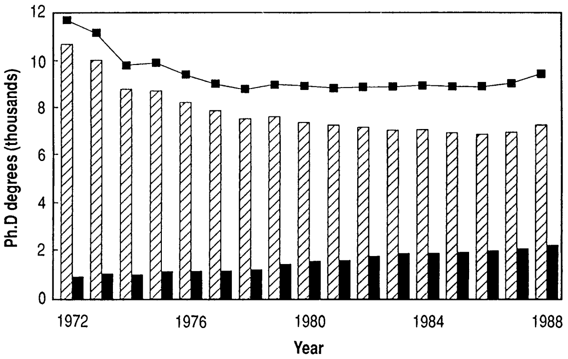

Fig. 10. Number of Ph.D. degrees awarded to U.S. citizens in the natural sciences and engineering from 1972 to 1988. Diagonal line bar represents men; solid bar, women; and squares, the total. [Source: National Science Foundation]

Underrepresented minorities, particularly blacks and Hispanics, present a more difficult challenge. Currently, these two groups make up 20% of the college-age population; they will make up 25% by 1996 and 33% by 2010. Thus, even a 5% conferral rate for baccalaureates in science and engineering will require substantially increased participation by such minority groups. At present, their participation is minimal. In 1988, fewer than 300 blacks and Hispanics received Ph.D.'s in science and engineering. No substantial improvement can be anticipated within the next few years. In fact, between 1976 and 1986 the percentage of black and Hispanic high school graduates going on to college declined, and both groups have significantly higher dropout rates than whites and Asians. The nation's schools must develop an environment that encourages minority students to pursue the sciences, one that is perceived as supportive and rewarding.

Concluding Remarks

Some may take comfort in the fact that conferral rates for baccalaureate degrees in science and engineering have remained roughly constant for 30 years. But any reasonable analysis of the realities of global competition in today's marketplace should be discomfiting in the extreme. The fact that the number of young people selecting science and engineering careers has not increased during a generation in which S&T pervades every aspect of our lives is nothing less than a scandal. A variety of reasons have been advanced; for example, uninteresting curricula in grades kindergarten (K) through 12 and teachers who are inadequately trained and poorly rewarded. Programs to deal with these problems have been discussed repeatedly, but few concrete steps have been taken. We need to redouble our efforts to ensure that all levels of government are committed to K through 12 programs and provide adequate support.

However, we need to do more than simply try to ensure adequate funding for programs that attract students to science and engineering. We also need to ask whether we, as scientists, are communicating, through our actions, the values that attracted us to science in the first place. Our universities take justifiable pride in the world-class research facilities on their campuses. Yet few research professors pay much attention to teacher training programs at their university, and fewer still would willingly sacrifice even a small percentage of their budget to improve such training programs.

Research universities take pride in the quality of the Ph.D. students they produce. Yet few of the research professors who bemoan the condition of precollege instruction in science would advise their graduate students to devote substantial time to the preparation of curriculum materials for grades K through 12. In addition, few advise seniors to consider careers in high school teaching.

These examples suggest the difficult choices we face in seeking to ensure the vitality of science and engineering in an era of limits. Obtaining funds to pursue even a fraction of the research opportunities on the horizon will be difficult. Finding trained scientists and engineers to further those opportunities will be a still more daunting task. There is little hope of securing the needed human resources unless we invest some of our current capital in their future.

Public support for science and engineering depends not so much on the discoveries and inventions produced, but on how closely the values of scientists coincide with those of the larger society. Those values are most evident to the public in our attitudes toward education. The title of the AAAS presidential address by Wesley C. Mitchell on the eve of World War II was "The Public Relations of Science" (*17*). Mitchell credited John Dewey, one of his mentors, with the assertion that "the future of democracy is allied with [the] spread of the scientific attitude" (*17*, p. 95). He went on to suggest what the scientists in his audience might do to act on Dewey's proposition (*17*, p. 95).

> As teachers in schools and colleges we can help thousands to develop respect for evidence. . . . We can promote general understanding of the methods and results of science through our own writings. . . . These things we should do, not as high priests assured that they are always right, but as workers who have learned a method of treating problems that wins cumulative successes, and who would like to share that method with others.

Those words, uttered on the threshold of World War II, apply with even greater force in our time as we move to the threshold of a new decade, a new century, and a new millennium.

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3. The 1945 proposal for a National Research Foundation envisioned an agency that would support research in all fields, including the military and public health. Estimates of the total budget required by the foundation to support all proposed functions during the first and fifth year, respectively, were $33.5 million and $122.5 million. Budget estimates quoted in the text were obtained by subtracting funds earmarked for military and health research from those figures.
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7. W. G. Bowen and J. A. Sosa, *Prospects for Faculty in the Arts and Sciences* (Princeton Univ. Press, Princeton, NJ, 1989).
8. As is customary in this type of work, I use the term "projection" rather than "prediction." The latter term implies that the model's output will actually be realized, whereas the former term carries a somewhat different meaning—namely, that the model's output can be modified over time if appropriate interventions occur.
9. Division of Policy Research and Analysis, National Science Foundation, *The State of Academic Science and Engineering* (National Science Foundation, Washington, DC, in press).
10. As noted earlier, the analyses presented in this paper focus on the natural sciences and engineering; they do not include the behavioral and social sciences (economics, political science, psychology, and sociology). Some observers believe that faculty shortages in those fields and in the humanities will be even more severe than in the natural sciences and engineering. Bowen and Sosa (*7*), for example, estimate that in the 1997 to 2002 period the candidates-to-jobs ratio for faculty positions will be 0.71 in the humanities and social sciences, 0.81 in mathematics and the physical sciences, and 1.13 in the biological sciences and psychology. As in any industry, the ideal job ratio would be roughly 1.3 candidates for each job.
11. The consequences of events associated with *perestroika* and Europe 1992 undoubtedly will influence these projections. It will be easier to recruit scientists from the U.S.S.R. and Eastern Europe to fill positions in the United States, and fewer American scientists will be involved in military research. On the other hand, Europe will become increasingly more effective as an economic power and the United States will have to increase its research investments to remain internationally competitive. No attempt has been made to model these variables, but I believe they will increase rather than decrease the demand for technical personnel.
12. K. C. Green, *Am. Sci.* 77, 475 (1989).
13. R. C. Atkinson, "The outlook for academic employment," paper presented at the stated meeting of the Regents of the University of California on 16 February 1989 in San Francisco.
14. The Association of American Universities (AAU) has recommended that the federal government take the following actions: (i) double the number of fellowships and traineeships; (ii) increase the number of research assistantships in federal agencies supporting academic research; (iii) expand incentives for underrepresented minorities and women to earn Ph.D.'s; and (iv) restore a comprehensive investment in university research by providing expanded, flexible support for research and direct funding for research facilities and instrumentation (J. Vaughn, "The federal role in doctoral education," a policy statement of the AAU, Washington, DC, September 1989).
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18. I am indebted to W. A. Blanpied for helping formulate many of the ideas presented in this article.