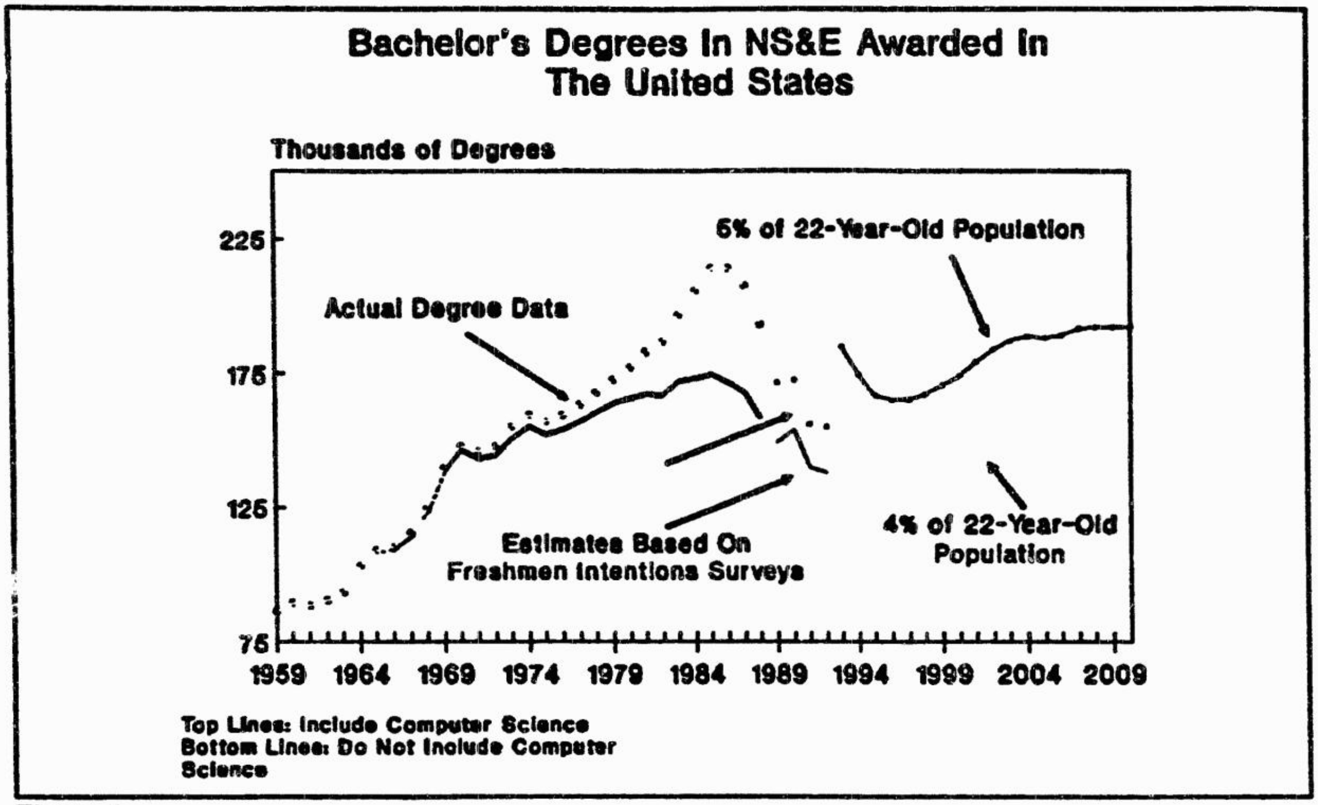

Figure 2

1984-86) as estimated by those projected to be produced (absent interventions) in the next fifteen years. It was calculated to be about 675,000 by the year 2006. This definition was used because, in the absence of a projection of demand for new NS&E bachelor degree holders, a constant level was assumed.

For PhD NS&E personnel, estimates of demand were made, based on historical relationships between R&D dollars in various sectors of the economy as well as enrollments for the academic sector. The shortfall in that case was defined as the cumulative difference between this history-based projected demand and history-based projected degree production. In reality the supply and demand equilibrate somewhere in the middle - so the shortfall concept is a way of expressing the probability of future substitution of resources away from new scientists and engineers, as well as future relative salary increases. For PhDs, the expected shortfall is exacerbated by the expected retirements of large numbers of existing PhD's in universities and in industry.

These two shortfalls can be expressed as very rough yearly targets: the U.S. could probably fruitfully use about 40,000 extra NS&E bachelor's degrees a year for the next 15 years, and about 6,000 extra PhDs a year beginning in the late 90's.

NATURAL SCIENCE AND ENGINEERING DEGREE PRODUCTION IN THE 1990'S

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INTRODUCTION

There is much debate now as to whether there are too many or too few scientists and engineers for the research funding and available positions for NS&E personnel. It is not within the scope of this paper to address such issues directly. Rather, we review existing trends in science and engineering degree production and discuss several events in the recent past and near future which affect this production. Since the number of science and engineering degrees awarded annually to our citizens may be related to the health of this country's science and technology base, the production of these resources warrants our attention. Although our data indicate that, at least for the next several years, annual Ph.D. production in NS&E fields will be adequate and possibly more than required to accommodate position openings for new Ph.D.s, availability of new NS&E graduates is expected to decline in the near future, and indeed already has declined at the baccalaureate level. Several important components related to U.S. NS&E production are examined in this paper.

The key event is a 25 percent reduction in the number of "college age" U.S. citizens, defined here as the 22-year-old population, during 1983-1996 after a doubling during 1961-1979. Thus, one-half of the demographically-driven increases of 1961-1979 in the annual number of NS&E bachelors degrees awarded will be lost during 1983-1996 as a result of the decline in the size of the traditional college-age population.

A second and related factor is the observed thirty-year "ceiling" of approximately 4.5 percent on the proportion of our 22-year-olds who are sufficiently capable of and interested in traditional natural science and engineering (NS&E) that they earn baccalaureate degrees in these fields.

Third, arguments that market forces will increase BS degree production beyond the "ceiling" to meet demand are not supported by experience. Comparison of the starting salaries of new NS&E bachelors-degree recipients and average starting salaries offered their peers in other fields reveals two distinct markets, with NS&E degree holders receiving a premium. Although the level of this premium shifts with time and there is some correlation between this shift and the number of NS&E BS degrees awarded, the shifts have never been sufficient to pierce the "ceiling" noted above. In fact, the number of BS degrees in NS&E has recently decreased, simultaneous with an increase in the number of bachelors degrees in other fields, in spite of markedly lower starting salaries for the latter.

A fourth concern is a near doubling of "replacement" demand (i.e., demand resulting from retirements) anticipated for Ph.D.-level natural scientists and engineers during 1990-2006 as the large number of Ph.D.s hired during the 1960s reach retirement age and the size of the "college age" population increases.

Finally, in some countries beyond our borders, particularly in Western Europe and to a limited extent the Pacific Rim countries, demographic trends mirror our own with respect to the decrease in their traditional college-age populations. Even with increases in the 22-year-old populations in some countries, estimates based on national B.S. degree production rates indicate that the net worldwide B.S. degree production may decline.

Because college attendance is a matter of individual choice and demand for technically trained employees depends on the state of our economy, it is not possible to affirm that observed trends in NS&E degree production will continue, or whether the supply of new scientists and engineers will be sufficient to meet market demands. However, absent any significant change in observed trends, it is likely that there will be fewer new NS&E B.S. and Ph.D. graduates coming out of the education pipeline in the years ahead.

Concern has been expressed that the expected number of new college- and university-trained scientists and engineers will be insufficient to meet national needs. If annual production of new NS&E scientists is desirable at the current or higher levels, then concerns are well founded and a sustained public policy response will be required over the next few years to draw a larger proportion of our college-age population into science and engineering disciplines.

THE PRODUCTION OF A SCIENTIST OR ENGINEER

In order to appreciate the complexity in projecting NS&E degree production, it is useful to look at the science and engineering "pipeline" as a whole. Data from three longitudinal surveys, conducted with support from the U.S. Department of Education, following three nationally representative samples of high school students for the 1972, 1980, and 1982 allow us to do this. The high school and post-secondary careers of these classes reveal the substantial distillation, or selection process that takes place to produce a doctorate in the natural science and engineering. These surveys were conducted under the support of the U.S. Department of Education. The first set of surveys is known as the National Longitudinal Survey (NLS). The NLS is the richest of the three data sets because it is the longest (spanning 1972-1986), the most detailed, and has the largest number of "panels" (points in time where members of the survey were surveyed again). The second and third sets of surveys are known as the High School and Beyond surveys (HS&B). The HS&B set based on the class of 1980 is the one used most heavily in this section. The HS&B data set for class of 1982 was used to characterize the constriction of NS&E-interested students from their sophomore year in high school through their freshman year in college.

Constriction of the Talent Pool

In 1980 there were approximately 3,650,000 high school sophomores. Of these, 700,000 had an interest in natural science and engineering another 500,000 or so were not yet permanently out of the NS&E pipeline. (See Figure 1.) However, only 260,000 had plans to attend a 4-year college and major in an NS&E field. High school age students are typically quite flexible in changing career intentions in response to new information and pressures. Only about 90,000 (35 percent) of the high school sophomores planning NS&E majors at 4-year colleges were still in the NS&E pipeline as high school seniors in 1982. The remaining 170,000 (65 percent) had altered their major plans. One-half shifted to non-NS&E fields and the other one-half changed college plans (deciding to attend a 2-year college, or to not attend college). A compensating 180,000 seniors had changed plans and decided on NS&E at a 4-year college rather than earlier plans to major in non-NS&E fields or not attend a 4-year college.

The transition from high school senior to college freshman year (1982-83) also witnessed major shifts. About 40 percent (115,000) of the 270,000 pipeline seniors either changed intended major (70,000) or did not enroll in a 4-year college. There was a partially compensating inflow of 90,000. The transition from freshman to sophomore year witnessed an outflow of 35 percent (85,000) of the 245,000 pipeline freshman, compensated by an inflow of 40,000, leaving the sophomore pipeline at 200,000. Inflows and outflows settled down after the sophomore year, with outflows somewhat greater. An estimated 180,000 bachelors in NS&E fields were earned by the high school class of 1982 by the start of 1988. Approximately another 25,000 bachelors will be earned by this cohort by 1994. These latter degree earners are a mix of returning pipeline dropouts and late pipeline entrants.

Despite the size of the inflows to and outflows from the NS&E pipeline, students are not shifting majors or dropping out randomly. Those who switch out of the NS&E pipeline into other majors do so because they find course work too difficult (31%) and because they find non-NS&E majors attractive (43%). Students switching into the NS&E pipeline from other fields do so because they think there are more jobs in NS&E fields (39%) and because they find the course work interesting (45%). Students completing college degrees in NS&E fields have been substantially above average in their measured high school performance. Seventy percent of the high school graduates of 1972 and 1980 completing bachelors had average high school grades of "A-/B+" or better. Over 90 percent of those members of the high school class of 1972 earning Ph.D.s in NS&E fields by 1985 had posted high school grades in this range.

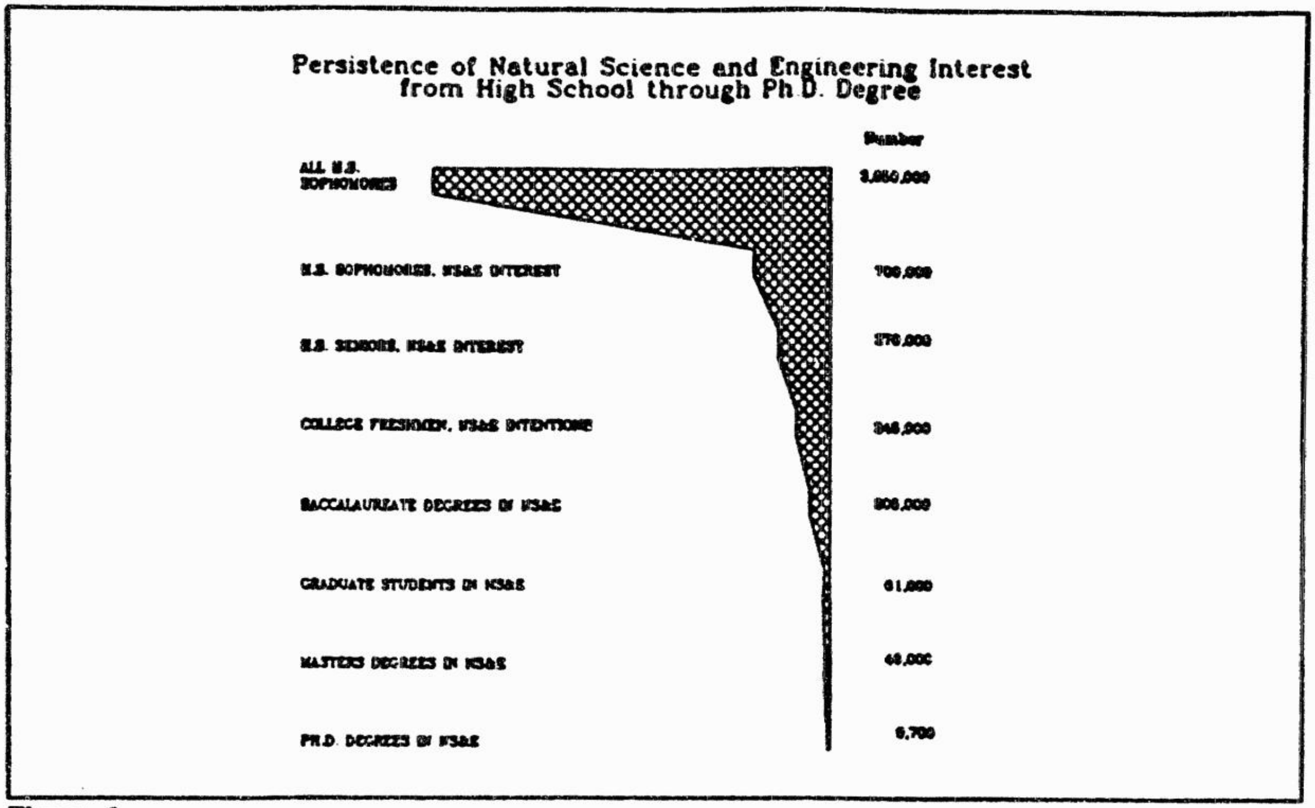

Figure 1

Loss of Able Students

Data from the Department of Education's sample surveys of the high school class of 1980 permit characterization of high school graduates by high school grades and by semesters of math and science courses taken. A student is judged to have been "apparently able" for NS&E course work at the 4-year college level if that student had a high school diploma, at least a "B+/A-" grade point average in high school, and had taken at least 10 semesters of math and science in high school. "Dropping out" of a planned four-year NS&E curriculum takes several paths. Some students merely shift from NS&E majors to another non-NS&E major, but remain in a 4-year college. Others drop to lower level colleges (2-year colleges and vocational schools), while the remainder do not attend college or drop out of college altogether.

Thirty-six percent of the high school graduates of the class of 1980 were "A" or "A-/B+" students. Of these students, 58 percent enrolled in 4-year colleges (16 percent were NS&E majors and 42 percent were planning majors outside of NS&E). One-half of the remaining 42 percent were enrolled in lower level colleges and the other 21 percent did not enroll in any type of college. This latter group of students leaving the educational pipeline was 30 percent larger than those in the NS&E pipeline.

Overall, 33 percent of the high school graduates of 1980 had taken at least 10 semesters of math and science. Sixty-two percent enrolled in 4-year colleges (20 percent planning NS&E majors) and 18 percent were not enrolled in college of any type.

Nonparticipants Over 25 percent of the non-college-bound high school graduates with high grades also had 10 or more semesters of math and science. Numerically, this group of students with both high grades and at least 10 semesters of math and science in high school was about 25 percent of the size of the group of all students still in the NS&E pipeline as college freshmen.

Junior College Graduates A similar conclusion is reached with respect to the good students ("A-/B+" or better grades and at least 10 semesters of math and science) who enroll in 2-year colleges rather than 4-year colleges. Two-year college students currently account for 15 percent of bachelors degrees in NS&E fields.

College Career Changes The loss of NS&E students from the freshman year in 4-year colleges is fairly severe. Only 40 percent of the NS&E freshmen from the high school class of 1980 who entered college immediately after graduation had earned a baccalaureate in science or engineering by the end of fall term/semester, 1985. Ten percent had acquired bachelors in outside fields and the remaining 50 percent were either still in college, temporarily out of college, or permanently out of college with less than a bachelor's degree. If the educational achievement of the high school class of 1972 is a guide to the eventual degree performance of the class of 1980, then by 1992 another 6 percent will have acquired B.S. degrees and another 6 percent will have earned bachelors degrees in non-NS&E fields.

Women and Minorities: The loss of NS&E students during college is greater for women than men, and greatest for underrepresented minorities. For students interested in NS&E majors in the freshman class of 1980, only 35 percent of females in that category had achieved an NS&E B.S. degree by January, 1986, compared to 43 percent of male freshmen interested in NS&E. Among minorities only 21 percent of NS&E freshmen had attained a B.S. by January, 1986.

Public versus Private Institutions: The type of college may make a difference. The completion rate for NS&E freshmen is higher in private colleges and universities, particularly for minority students. Part of this higher completion rate is attributable to the greater average ability of students that attend private rather than public colleges, but part may be due to the better teaching and additional time faculty spend with students in private colleges. For minority students, the NS&E bachelors completion rate is 53% higher for NS&E freshmen attending private colleges than for public colleges. The NS&E bachelors completion rate is 24% higher for white and Asian students at private schools.

Trends in Retention of NS&E Students Field switching out of NS&E may be levelling off, based on information derived from a survey of the high school class of 1980. While few have obtained terminal graduate degrees yet, that group has already achieved the same fraction of enrollment in NS&E graduate studies as the class of 1972. But employment data still show a major shift away from formal scientist or engineer jobs. Sixty-six percent of the NS&E graduates from the high school class of 1980 were full-time employees in 1986, but only about half of them were in NS&E jobs.

NS&E BACHELORS DEGREE PRODUCTION

Although many factors enter into the process of choosing a career, several of which have changed substantially over the last 30 years, annual production of NS&E bachelors degrees has been relatively constant as a proportion of the 22-year-old age cohort over that period. Although the total population will continue to rise, the dip in the number of people in this cohort will affect the replacement capacity of our society in terms of newly trained youths for almost two decades. (Figure 2).

If we look at the participation of U.S. citizens in the attainment of bachelor's degrees in all fields, the rate grew by about 4% annually for around sixty years and then slowed to less than one percent. The long term participation rate in NS&E fields, as college participation rate in general, increased steadily

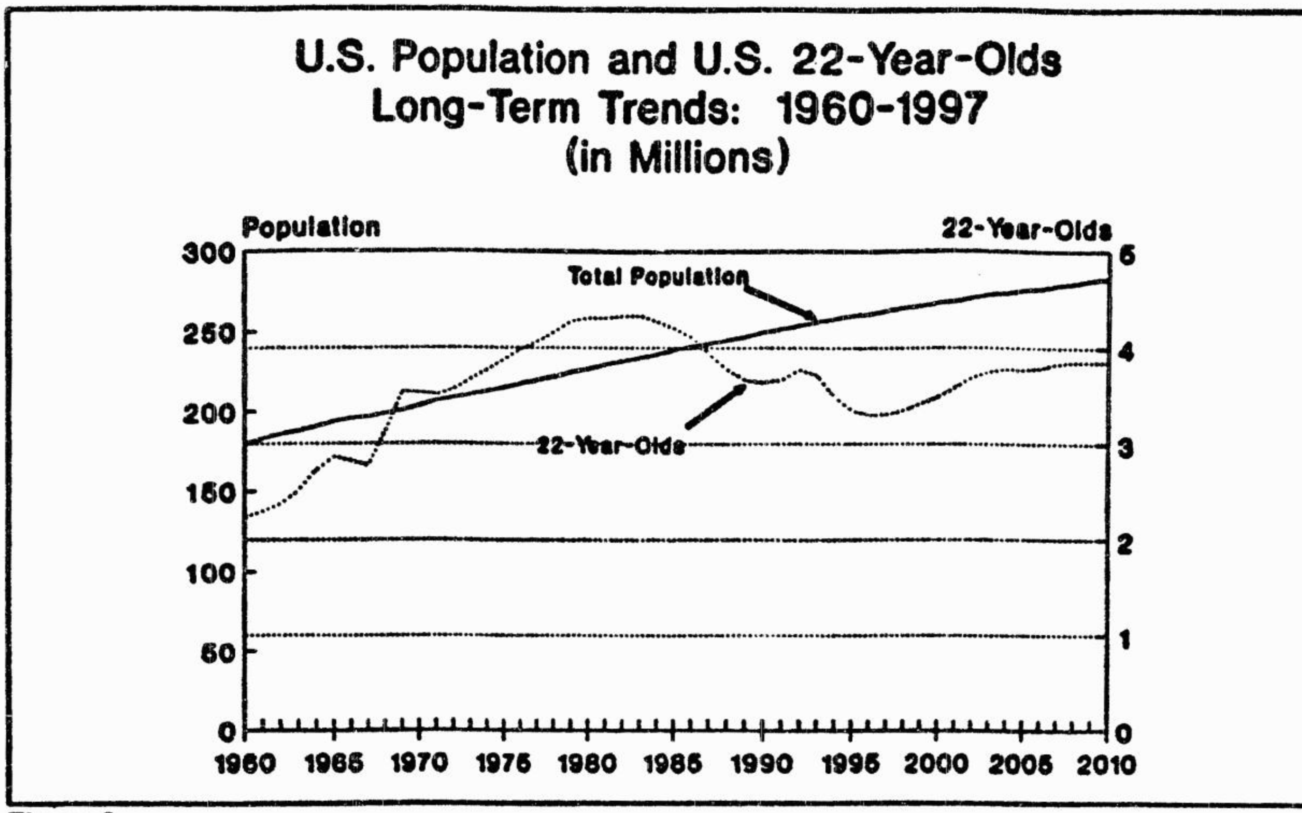

Figure 2

through the years, growing at an annual average of about 3% through the late 1950s. It then levelled off at about 4% to 5% of the relevant age cohort.

The stability of the percentage of 22-year-olds earning bachelors in NS&E fields during the 1960s led Wallace Brode to speculate in 1971 that the production of these degrees had reached a saturation level, which he identified as 4% of 22-year-olds. (See: "*Manpower in Science and Engineering, Based on a Saturation Model*", *Science*, July 16, 1971.) Brode suggests that the 4% figure represents a limit on the ability of the Nation to recruit all able interested primary/secondary school students into NS&E majors in college. He further suggests that the recruitment activity is the primary determinant in election by qualified individuals to pursue a degree in NS&E, with feedback from fluctuating demand playing a much less important role.

Empirical evidence since publication of Brode's hypothesis supports his observation of stability in the proportion of the age cohort interested in and capable of earning degrees in NS&E fields. Even though the demographic base of college students broadened in the 1960s and again in the 1980s, most notably with respect to gender, as Figure 3 shows, the number of B.S. degrees awarded in NS&E closely followed the variations in the size of the 22-year-old population.

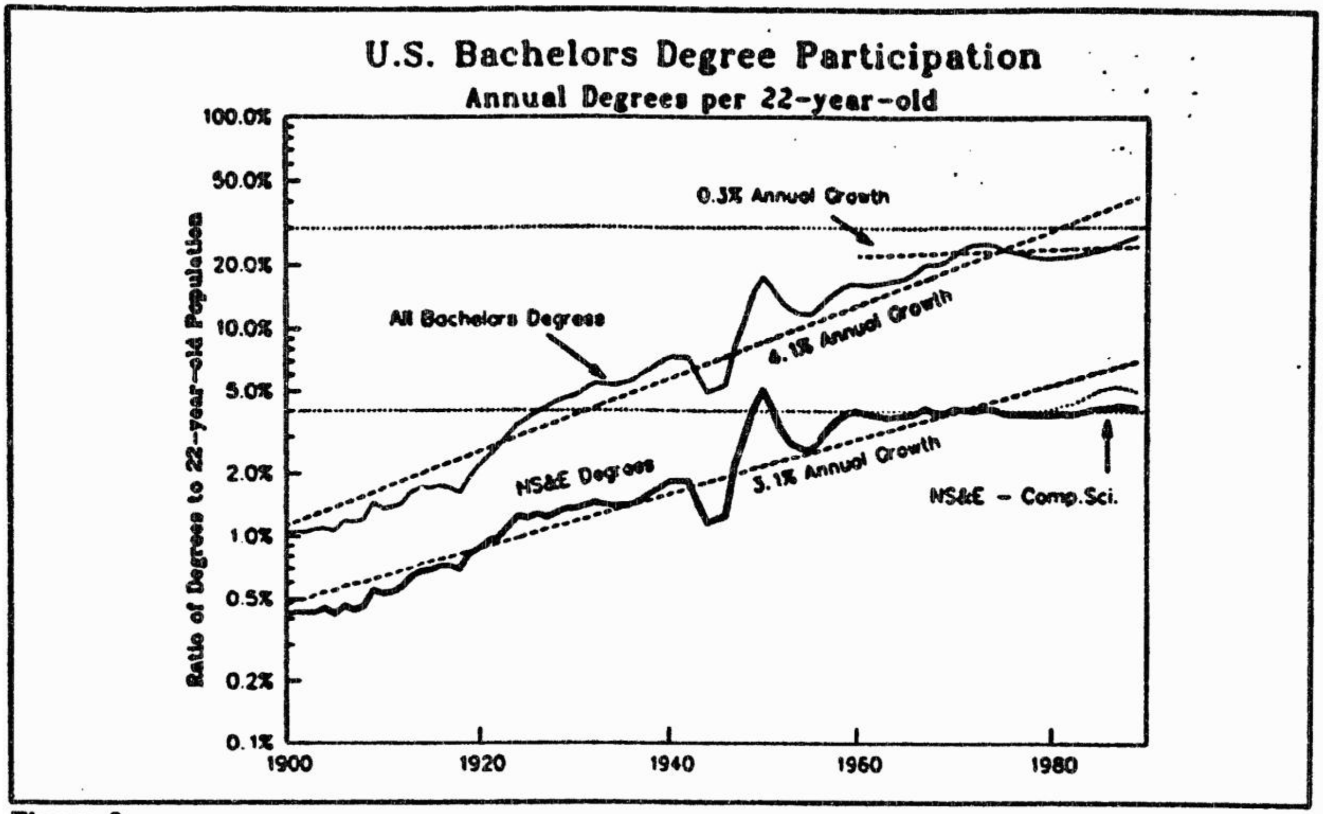

Figure 3

Decline in Freshman Interest

Historically, annual freshman intentions surveys, conducted by the American Council on Education (ACE), have been good predictors of NS&E bachelors awarded three years or so later (see annual issues of *The American Freshman: National Norms)*. Since the early 1970s, freshmen "intentions" about their major have explained about 90% of the variance in the number of NS&E degrees three years later.

Freshman intentions data for the period 1985-89 and college enrollment data were used to extrapolate bachelors production for the years 1989 through 1993. These extrapolations presage a decline of 12 percent in NS&E bachelors during 1988-1993 (expected to drop from 5.1% to 4.5% of 22-year-olds).

A recently completed study by the Educational Testing Service (ETS) of SAT test-takers is in broad agreement with the ACE data. It found that the percentage of college-bound high school seniors intending to major in a "quantitative science" field (defined as all NS&E fields except the life sciences) dropped from a high of 19% in 1983 to 13% in 1988 (see *ETS Policy Notes*, June 1989). Most of this drop is due to reduced interest in computer science.

Field Composition of NS&E Bachelors Degrees

If NS&E fields are separated into four major components–engineering, computer science, physical sciences, and life sciences–trends in bachelors degree production can be observed to vary considerably (see Figure 4). In particular, the relatively new field of "computer science" has had a significant impact on the stability of the ratio of NS&E B.S. awards to the number of 22-year olds.

From the early 1970s until the early 1980s, the number of individuals receiving computer science degrees was relatively small, and these students seemed to be coming from the same pool as other NS&Es, particularly those interested in mathematics. The substantial growth in these degrees from 1980 to 1986, combined with the increased in the percentage of 22 year olds getting bachelor's in NS&E in that period suggests that recipients have been drawn increasingly from the pool of students who previously were not candidates for NS&E bachelors degrees. For example, they are awarded disproportionately by colleges with little or no research and development activity, few or no Ph.D. programs, and below average percentages of total bachelors in NS&E fields. A rise in participation in NS&E fields taken as a whole, observed since the late 1970s, reflecting computer science majors, has begun to reverse itself in the last few years. When computer science B.S. degrees are included, the annual production of B.S. degrees in NS&E has ranged from a low of 3.7% of 22-year-olds in 1963 to a high of 5.3% in 1987. Production has since declined to 5.0% in 1989.

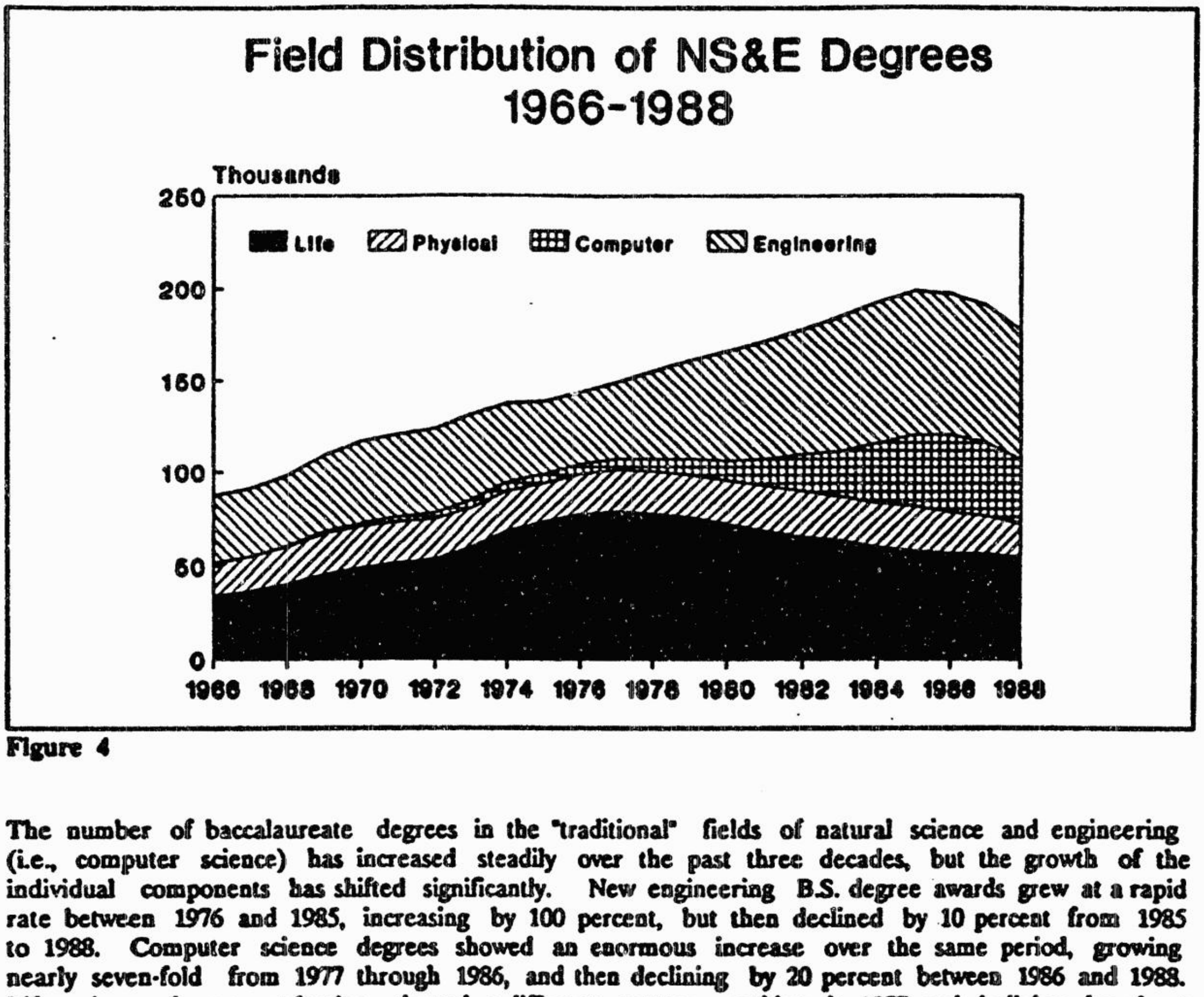

Figure 4

The number of baccalaureate degrees in the "traditional" fields of natural science and engineering (i.e., computer science) has increased steadily over the past three decades, but the growth of the individual components has shifted significantly. New engineering B.S. degree awards grew at a rapid rate between 1976 and 1985, increasing by 100 percent, but then declined by 10 percent from 1985 to 1988. Computer science degrees showed an enormous increase over the same period, growing nearly seven-fold from 1977 through 1986, and then declining by 20 percent between 1986 and 1988. Life science degree production showed a different pattern, peaking in 1977 and declining by about 31 percent between 1977 and 1988. Physical sciences show a similar pattern, peaking in 1982 with about 14 percent of all NS&E degrees, and thereafter declining about 27 percent by 1988.

Market Effects

Without some positive action to substantially reverse the decline in student preferences for choosing NS&E majors, bachelors degree production in the fields of natural science and engineering will likely decline. Based on observations from the past decade, it appears unlikely that the labor market for NS&E bachelors graduates can, by itself, address these emerging events by steering an adequate number of undergraduates into NS&E majors.

The participation rate for NS&E degrees (excluding computer science) has remained fairly constant at 4.5 percent during a period with significant and increasing starting salary premiums for NS&E bachelor degree holders. It appears that when increasing numbers of eligible students enroll in one NS&E field, they are generally offset by declines in student participation in other NS&E fields. Only in the computer science field is there strong evidence of market responses which are not offset by declines in other NS&E fields.

The market for new bachelors degree graduates is complex. In fact, at least two separate or segmented markets can be identified from starting salary data (Figure 5). Starting salaries for natural scientists and engineers are considerably higher than for other baccalaureate degrees. Education majors appear to have comprised a third group during the 1960s and 1970s, but differences in starting salaries for education bachelors degrees and other non-NS&E degrees have almost disappeared during the 1980s.

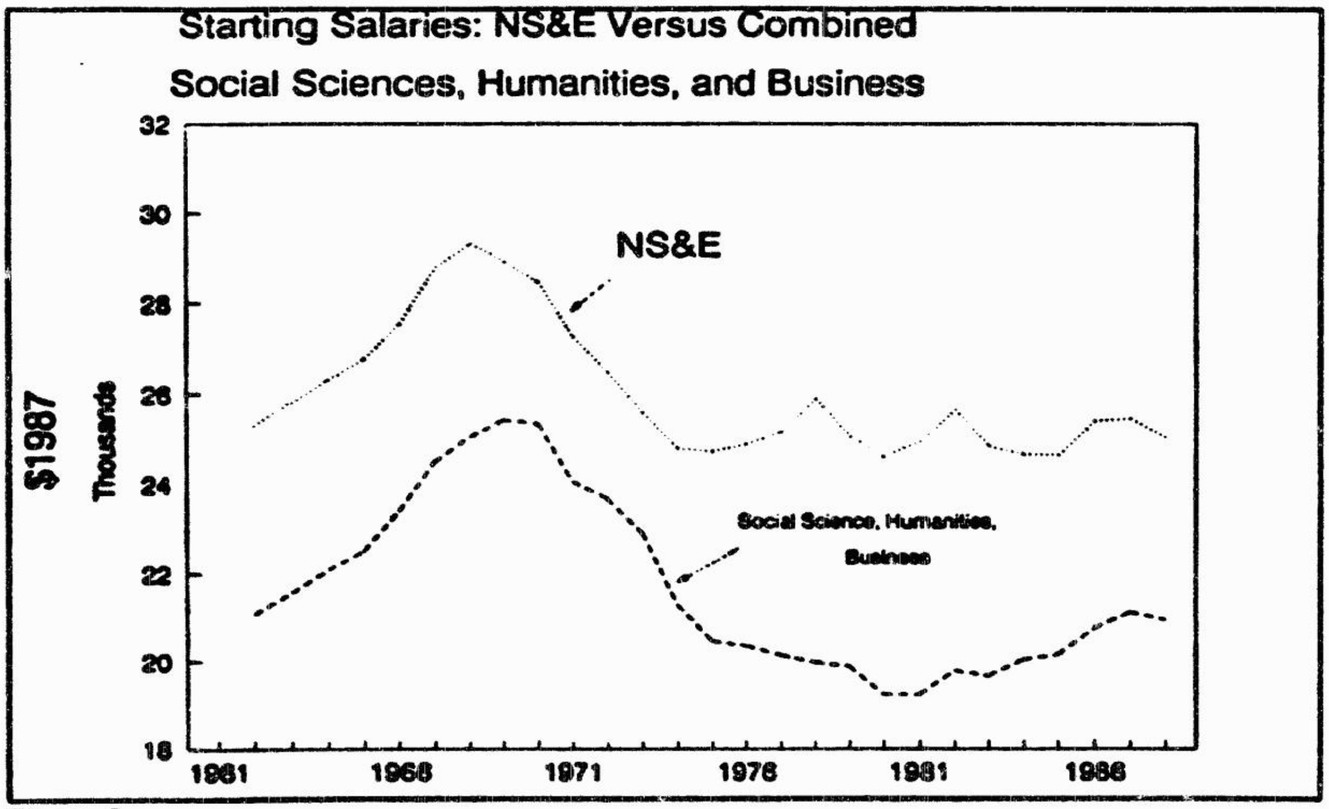

Figure 5

Market phenomena explain some but not all of the shifts in degree patterns observed during the past several decades. For instance, the large relative (and absolute) increase in liberal arts bachelors degrees during the past two decades has occurred despite an increasing premium for NS&E degrees.

Much of the increase in liberal arts bachelor degrees has been due to the influx of women and minorities, groups whose viable alternatives may have been an education degree rather than an NS&E degree. In fact, as the number of liberal arts bachelors has increased relative to the number of education bachelors, the starting salary premium for selecting a liberal arts degree over an education degree has almost disappeared, suggesting that movement of individuals across these separate markets has converted it into a unified market.

Starting salaries, however, are not the sole economic signals affecting degree choice. Lifetime income, or expected lifetime income, may not necessarily be closely correlated with starting salaries and may have a stronger influence on career choice. For example, the evident experience premium for middle-aged business majors who graduated in the early 1960s is higher than the experience premium for engineering graduates from the same period. Another factor affecting career choice is potential maximum incomes of the profession, rather than starting or average salaries. A few individuals in business, law, and medicine have extremely high incomes, although the average of all persons in those occupations is much lower. The potential for these extraordinary compensations seems to entice many people to pursue training in such fields.

Growing Participation by Women

There has been a slow but persistent rise in the rate of conferral of NS&E baccalaureate degrees to women, from less than 1 percent of female 22-year-olds in 1959 to 3.2 percent in 1986, 1987, and 1988. During 1972-1982 annual awards of NS&E B.S. degrees to females grew steadily from 1.5 percent to 2.4 percent of female 22-year-olds. In the first five years, the growth in NS&E bachelors degrees awarded to women was entirely in the life sciences, while in the latter five years it occurred entirely in the remaining NS&E fields.

During 1982-1986, more than one-half of the growth in NS&E bachelors degrees awarded to women was in computer science. In 1982, the conferral rate to women in this field alone was only 0.3 percent of female 22-year-olds, compared to 0.75 percent in 1986. During 1986-1988 this rate declined to 0.6 percent of 22-year-old females.

The rise in participation in NS&E by females was offset in large measure by a decline in the conferral rate to males, from 7 percent to 6 percent of male 22-year-olds during the 1972-1982 period. The increase in computer science bachelors awarded to males pushed the aggregate NS&E conferral rate to males from 6 percent during 1980-1982 back to 7 percent during 1986-1988.

Minority Participation

In 1985, blacks accounted for 13 percent of 22-year-olds but only 5 percent of NS&E bachelors, and Hispanics accounted for 8 percent of 22-year-olds, but only 3 percent of NS&E bachelors. College age blacks and Hispanics are expected to increase their proportion of the total college-age population from about 23 percent currently in 1989 to 28 percent or more in the year 2000, and 30 percent or more in 2010, according to the Bureau of the Census.

NS&E Bachelors Degree Production Worldwide

A recent look at the population distributions of 29 countries for the next two decades shows that many nations are experiencing a dip in the 22-year-old portion of their populations. Although it is significantly more difficult to link their population data to participation rates, extrapolation using current rates suggests that the production of countries that have increasing populations of 22-year-olds will roughly offset the decreases that will be experienced by those in decline. The relative need for such degrees is, of course, speculative, but the rough indicator of availability is instructive for those who feel that immigration will be a reliable source of scientists or engineers in the years ahead (Figure 6).

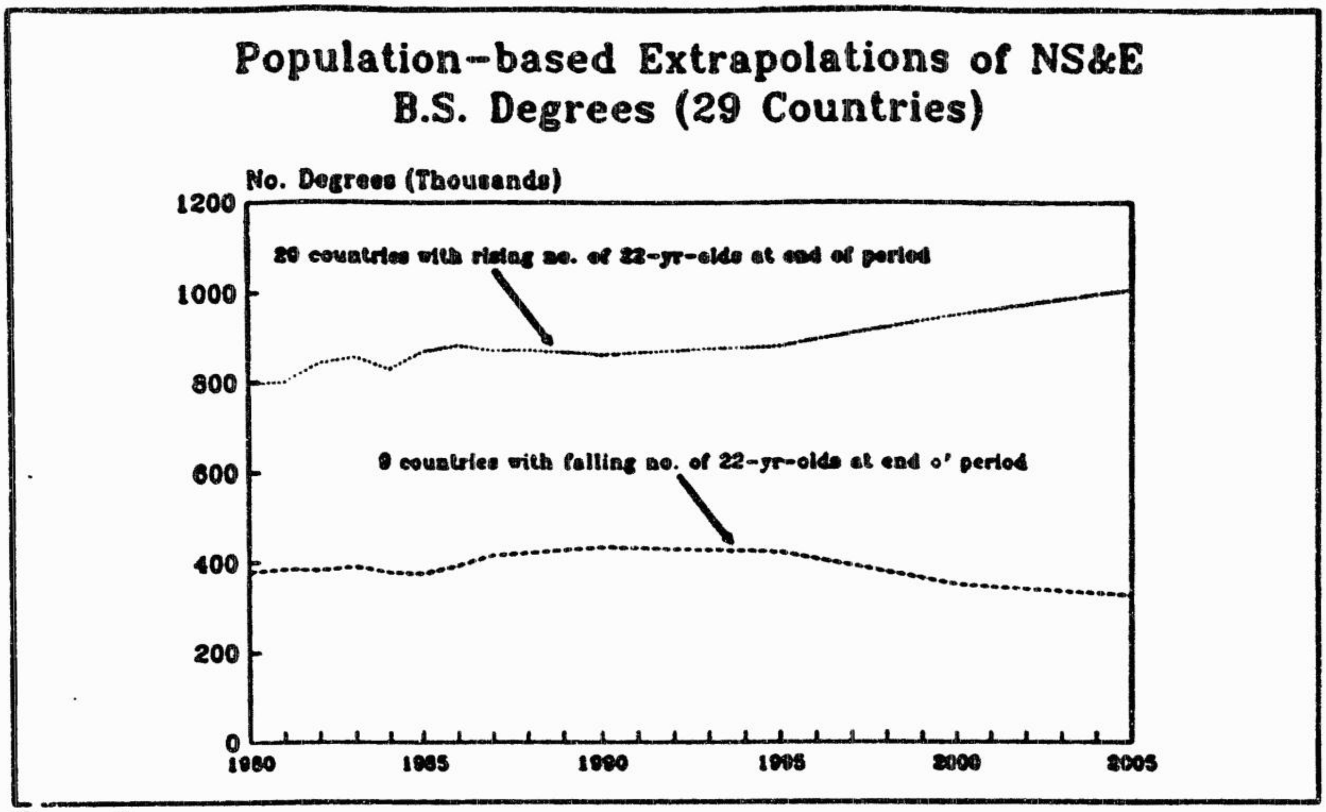

Figure 6

PH.D. DEGREES

The Ph.D. degree production rate is more clearly affected by market factors than NS&E B.S. degree production, but it responds with a lag because of the long time required to obtain a Ph.D. degree. Moreover, in professional disciplines, particularly Ph.D. scientists and engineers, occupational shifts are not easily accomplished.

The connection between pursuit of the Ph.D. and market stimuli has been progressively weakened since 1968 by a rise of 1.2 years in the average time from bachelors to Ph.D., and by increases in the tendency of new natural science and engineering Ph.D.s to take post-doctoral positions as first jobs. The percentage of new Ph.D.s taking post doctoral positions (as reported by annual SED data collected by the NAS in seven fields combined that account for about 80% of NS&E Ph.D.s) jumped from 21% to 34% during 1968-1972 as the job prospects for new Ph.D.s worsened substantially. During 1972-1980 this post-doctoral percentage rose more slowly to 44%. Since 1980, it has risen very slowly to 49%. Possibly post-doctoral training has become another step for Ph.D.s seeking tenure-track academic positions in major research universities in the physical and life sciences.

There is no convincing evidence of a historically fixed link between bachelors and Ph.D. degree production despite the relative stability of the ratio of NS&E Ph.D.'s to the number of N&E bachelors degree granted eight years earlier (at 5 percent) over the last ten years. Examined over a longer period of twenty years, the ratio has varied widely. It is difficult to measure real continuation rates from a particular NS&E bachelors cohort to the doctorate with precision, due to the wide age distribution of Ph.D. recipients (90 percent of whom are 25 to 37 years old) compared to bachelors recipients (90 percent of whom are 21 to 24 years old). Nonetheless, trends in the mean and median ages of new Ph.D.s, coupled with annual bachelors and doctorate graduation figures and bachelors to Ph.D. crossover tendencies, permit calculation of approximate continuation rates. These rates rose substantially during the 1960s and reached a peak considerably above 10 percent in 1971 and 1972. After that, continuation rates dropped substantially until 1977, to about 6 percent. In this paper, we have used the simple ratio of Ph.D.'s to bachelors granted 8 years earlier to represent combined continuation ratio.

During 1977-1985, continuation rates across all fields of NS&E combined dropped slowly to about 5.2 percent, and during 1985-1988 leveled off or recovered slightly, back to 5.5 percent. But because the mix of bachelors degrees has been shifting towards fields with lower-than-average continuation rates (e.g., most engineering fields and computer science), the overall continuation rate has remained unchanged in the neighborhood of 5+ percent. In this paper, we have use the simple ratio of Ph.D.s to bachelors granted eight years earlier to represent combined institution rates.

The major reason for the reduction in continuation rates is a reduction in demand for such specialized skills. Ph.D. level training is required primarily for upper level college teaching and for basic and applied research in universities, industry, and government. These needs have vacillated over the last 30 years. When needs plateau or decline, job vacancies are reduced to replacement positions for retirees or less.

Foreign Students

Although Ph.D.s trained in foreign universities have not been a significant source of new NS&E personnel, foreign doctoral students studying in U.S. universities have been a significant source of supply of NS&E doctorates. In 1988, these foreign students accounted for more than 28 percent of new NS&E Ph.D.s, and 15 to 20 percent of additions to the U.S. NS&E Ph.D. labor force. U.S. annual Ph.D. production in all fields of NS&E approximately tripled between 1960 and 1971 to almost 14,000, dropped gradually until 1978, then slowly recovered during 1978-88 to 14,600. Most of this recovery was due to a rise in Ph.D.s conferred to foreign citizens who were in the United States on temporary student visas. Annual awards to foreign students jumped to 4,390 in 1988, an increase of 470 over 1987.

A key issue for the future is the trend of foreign Ph.D. production in U.S. universities, and the role of foreign doctorates in the U.S. system of education and research. The U.S. retains about half of the foreign-born Ph.D. candidates as members of the workforce, and retains most of the doctorates earned by holders of permanent resident visas.

It is generally possible for a newly graduated Ph.D. of foreign citizenship to acquire entry level positions in the U.S. labor market under current immigration practices. The recent changes to the immigration law make it easier to offer citizenship to foreign nationals who have skills which are in scarce supply or for other reasons, highly desirable.

PROJECTED FUTURE DEMAND FOR NS&E'S

This paper has purposefully avoided making projections of the future demand for NS&Es even though this information would be valuable if it were reasonably accurate. Future demand is clearly important in determining precisely the adequacy of expected future degree production. However, such estimates depend on extraordinarily complex estimation procedures, which are still captive to key assumptions. Key factors affecting future demand which must be "predetermined" (assumed or independently estimated) are the rate of growth of GNP (and key subsectors of the U.S. economy), independent changes in spending on R&D (especially, changes in defense R&D spending), and changes in how natural scientists and engineers are used in R&D and other activities.

Using "best-practice" forecasting techniques, Science & Engineering Indicators - 1989 has offered the projection that U.S. private industry will create 600,000 more jobs for S&Es during 1988-2000, an increase of 33 percent over the 1.9 million S&E jobs extant in 1988 in private industry. This projection uses the "mid-level" growth rates for key variables, and an occupational structure matrix developed by Bureau of Labor Statistics to translate total employment projections into S&E employment projections. What are the high and low boundaries surrounding this projection between which we can be highly certain actual job growth will fall? The answer requires us to consider that the growth rates identified as "mid-level" in 1988 may be considerably higher than 1991's consensus mid-level rates. Furthermore, technological change has been found to be a larger source of growth in employment of S&Es in the past than simple economic growth. But technological change has not occurred smoothly or predictably. Consequently, actual employment growth of S&Es during 1988-2000 may turn out to be much smaller or much larger than 600,000.

Bachelors Degree Projections The 25 percent decline in the number of 22-year-olds over the 1983-1996 period is the primary cause of the anticipated decline in NS&E bachelors degrees. The projections in this paper assume that the declining participation rate will level off at 4.5 percent of 22-year-olds. The number of BS degrees in all fields of NS&E grew about 3 percent per year during the period 1977-1985, but declined at the same rate since then. During the 1986-88 period, bachelor's degrees in NS&E fields dropped by 21,000, equivalent to 10 percent of the 1986 total.

The reasons for decline in proportion of 22-year-olds pursuing an NS&E degree are not at all clear. The data on characteristics of college students gives some insights however. The "typical" college student of the past was a white male, who enrolled in college immediately after high school and earned a bachelors degree four years later. Today there are increasingly fewer students fitting this stereotype, and the expanding female and ethnic group components of college enrollments traditionally have had less interest in science and engineering curricula.

Ph.D. Production Market conditions and demographic trends will affect future supplies of Ph.D.s. Ignoring market effects, if the rate at which B.S. graduates pursue the doctorate remains fixed at current rates in Natural Science and Engineering and if the number conferred to foreign citizens remains unchanged, then the number of new NS&E Ph.D.s will rise slightly until 1993, and then decline rapidly through the first decade of the next century.

It is difficult to predict with any degree of certainty the need for NS&E Ph.D.s. New Ph.D. scientists and engineers are needed to replace those leaving the professions and to expand the growth sectors of the economy. Figure 7 shows an estimate of the replacement demand for academia, business and industry, and other (including government) sectors. Replacement is principally for retirements, which are rising in all sectors. Currently, about 5,000 positions become available annually due to deaths and retirements of NS&E Ph.D.s. This source of job openings is expected to rise to 6,000 in the mid-1990s and to accelerate to 8,000 at the end of this century and to 10,000 in 2006. Replacement demand for faculty will increase substantially, from about 2,900 at present to about 5,700 in 2006.

Demand for new Ph.D. positions is driven by the growth of research and development expenditures and the salaries commanded by Ph.D. graduates. Ignoring the market effects on salaries, an upper bound on demand can be calculated from assumed growth rates in R&D expenditures and assumed higher education enrollment rates. The top curve in Figure 8 assumes continued growth of R&D extrapolated from the last 20 years. Again ignoring market effects, a "business-as-usual" projection

Expected Replacement Demand for NS&E Ph.D.s During 1988-2006 By Sector

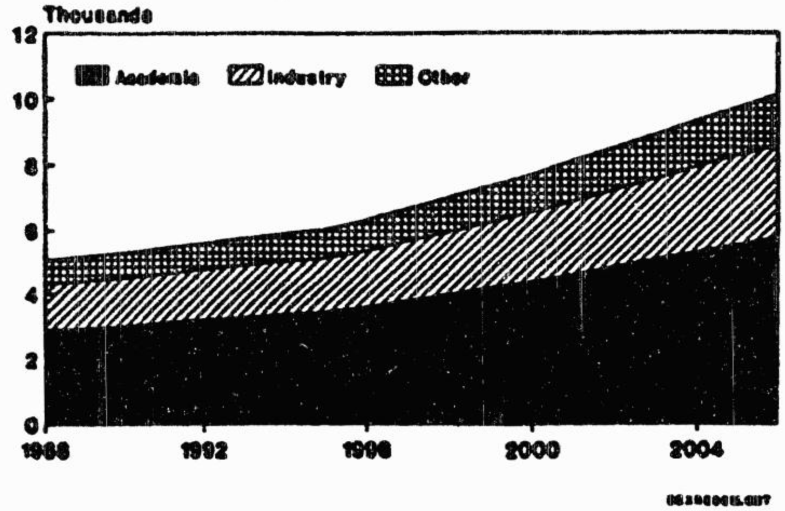

Figure 7

of Ph.D. graduates can be made, as shown by the middle curve in Figure 8. A lower estimate of demand is also shown, which assumes zero growth after 1999, with growth in R&D tapering off gradually before that time, so the demand is only replacement of persons leaving the workforce after 1999.

The ultimate resolution of supply and demand occurs through the workings of the market. But the market response for new Ph.D.s occurs with a considerable lag, as it takes about eight years beyond the B.S. to earn a Ph.D. Many complications result from this lag. For example, no growth in demand for new Ph.D.'s sends a signal discouraging pursuit of Ph.D.s. by eligible NS&E B. S. graduates. Such a signal may well reduce the number of new Ph.D.s eight years later, a time forecast to "need" significantly more Ph.D.'s in the future, when needs are projected to climb. A further complication to estimating the future supply and demand for new Ph.D.s is whether the present 50 percent rate of absorption of foreign students into the labor force will be maintained.

SUMMARY

Empirical evidence suggests the possibility that the rate of NS&E B.S. degree conferral to 22-year-olds will continue to fall for the next few years. Projections in this paper assume that the average percentage of 22-year-olds earning bachelors in all NS&E fields (including computer science) will decline after 1991 to 4.5% by 1998 and remain at that rate thereafter. If this participation rate remains constant as assumed, the factor controlling future supply of new bachelors-level scientists and engineers is the size of the pool from which they are drawn.

The picture is more complex for the supply of new science and engineering Ph.D.s. Estimates of "needs" indicate current annual awards of Ph.D. degrees are adequate in the near future, until around 2004. However, should research growth increase at the same level as it has over the last 20 years, annual awards of NS&E Ph.D.s degrees at the projected level will be increasingly below "needs" after 1993.

NEW NS&E PH.D. AWARDS AND NUMBER OF POSITIONS UNDER TWO ASSUMPTIONS

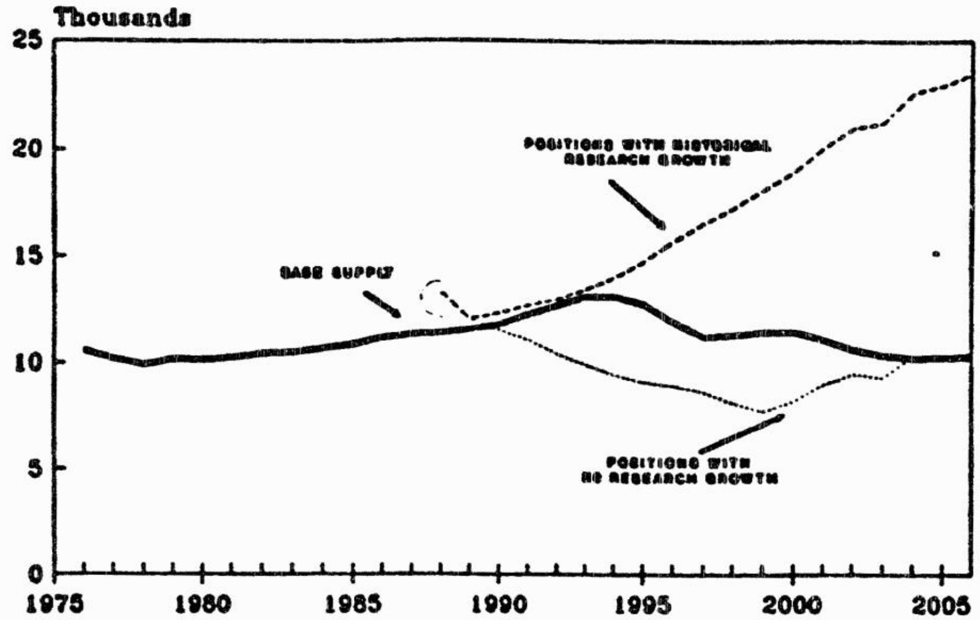

Figure 8

Any portion of the analysis thus far could be questioned by those who feel assured that future events will occur to modify historical patterns. There is no compelling argument that past behavior will continue, regardless of how persistent the past behavior has been. But those who argue for the occurrence of institutional change must surely present more evidence than enthusiastic belief in their position. On the other hand, over the long term in a market economy the society will get what can afford to buy. Public policy becomes operative when market response is considered inadequate. Figure 9 illustrates some of the trends discussed in the early part of this paper and other trends in our economy related to "needs" for scientists and engineers:

- Total population will continue to grow throughout the century, meaning that the economy will still have to support an expanding consumer market.
- R&D in constant dollars also shows a long-term growth trend, though it has never reached its earlier 1960 levels.
- GNP has also continued to grow over this century. High technology industries have become increasingly important to the economy.
- The stock of NS&E B.S. and Ph.D. degree holders has continued to grow.
- The total number of bachelors degrees awarded annually has continued to grow.

The future being, by definition, unknowable, allows all sorts of possibilities as to how technologically dependent or sophisticated we will be and what this will mean for our education system. This analysis

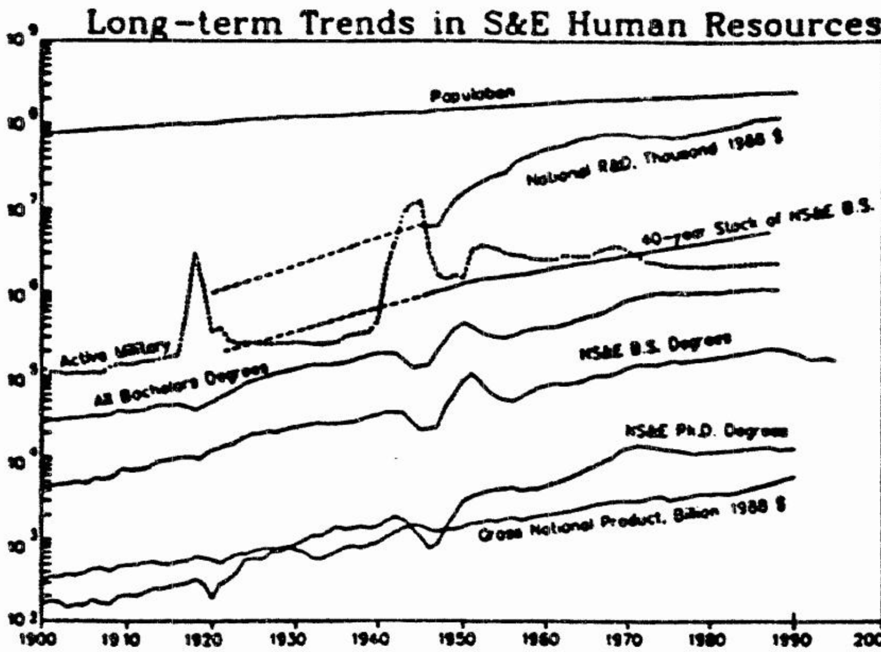

Figure 9

depends on knowledge of the past and the present trends in new NS&E degree production and employment. The question of whether we will "need" a specified number of new NS&E degree holders in future years depends on the relative rates of growth of our economy in areas requiring specialized scientific and technical knowledge. Whether our education system is able to adequately respond to such "needs", or whether intervention from the public sector is desirable, are open questions.

APPENDIX 5

Additional documentation of use of NSF draft reports.

Meeting the Needs of a Growing Economy: The CORETECH Agenda for the Scientific and Technical Workforce

CORETECH

COUNCIL ON RESEARCH AND TECHNOLOGY

CORETECH

COUNCIL ON RESEARCH AND TECHNOLOGY

Executive Summary

For some time, the United States research community has been concerned about the education and training of America's current and future scientific and technical work force. We are pleased to hear leaders in the new Administration and Congress express similar concerns, and we look toward the 101st Congress with hope that steps can, and will, be taken to provide high-quality science, mathematics, and technical education for all our nation's children and for our work force.

The Council on Research and Technology (CORETECH) has a number of key priorities on its public policy agenda for 1989. This year and beyond, we seek long-term stability in U.S. public policies that affect R&D. In part, this stability will be reached through a permanent R&D tax credit, permanent resolution of the disincentive problems with Treasury Regulation 1.861-8, funding for modernization of university research facilities, and doubling of the National Science Foundation budget by 1993.

Enhanced science, mathematics, and engineering education fits well within CORETECH's general public policy agenda because better education and training also relate to the long-term foundation that must be laid in order for the United States to maintain its technological world leadership. As the work of the new Administration and the 101st Congress progresses, CORETECH will continue its efforts to identify specific measures that may improve the training of our scientific and technical work force.

Since early 1988, the 161 universities, corporations, research institutes, and associations that comprise CORETECH have been discussing education and training of the scientific and technical work force. In order to share our deliberations with p makers, as well as with other members of the research comn ty, we have prepared the following position paper. It high' some of the problems that we have experienced as most pres and includes recommendations to address these problems.

CORETECH is particularly pleased to have the endorsement of the Council on Competitiveness, which supports the findings and five broad recommendations set forth in the enclosed statement. We are appreciative of their assistance in bringing this position paper to the attention of policy makers and educators, and for their support in the dissemination of the document to the American public.

There are numerous indications that the education of our current and future scientists, engineers, and technicians is inadequate:

Under present circumstances, projected student demographic trends will not produce enough scientists and engineers to meet the nation's needs. Moreover, the number of current science and engineering undergraduate and graduate students is decreasing, while federal financial support for undergraduate and graduate students has fallen dramatically.

In addition, we face a shortage of faculty in key scientific and technical fields, and academic research facilities are deteriorating.

Pre-college science and mathematics preparation is alarmingly inadequate, and at the other end of the scientific and technical work force pipeline, opportunities for career-long continuing education are insufficient.

Corporate managers of technology are one of the most critical links between innovative research and commercial application. However, opportunities for career-long education in technology management are inadequate.

To find permanent solutions to these problems, we all must work together. Yet, coordination among key decision makers is often deficient.

Corporations, universities, state and local governments, and professional societies share a great deal of the responsibility for high-quality education of the work force. The CORETECH position paper discusses how companies and universities can fully contribute to this education and training. In addition, it recommends that the federal government take the following steps:

1. Focus appropriate attention and resources on federal mechanisms to bolster elementary and secondary science and mathematics education, recognizing that the foundation laid by early education is critical to the entire scientific and technical pipeline and that the primary responsibility for the United States' elementary and secondary education system lies with state and local government.

2. Substantially increase support for undergraduate and graduate education in the sciences and engineering and for modernization of university research facilities.

3. Expand programs to raise the percentage of women and minorities in our scientific and technical work force.

4. Support, and stimulate, career-long continuing education programs.

5. Foster communication and collaboration among government, industrial, and educational partners to maintain the excellence of our scientific and technical work force.

Training of the scientific and technical work force is too important to our economic and general welfare, and to our national security, to be neglected. We face significant shortages in the supply of highly-trained scientists, engineers, and tech. .ians. In addition, we need to greatly improve the scientific and technical literacy of the overall population. We urge our national leaders to join with us in these efforts.

Dr. Roland W. Schmitt
Chairman (Rensselaer Polytechnic Institute)

Admiral B.R. Inman
Vice Chair (Westmark Systems, Inc.)

Dr. Stanley O. Ikenberry
Vice Chair (University of Illinois)

Dr. Jane Armstrong
Vice Chair (Houston Research Center)

George T. DeBakey
Vice Chair (ADAPSO, Inc.)

Peter F. McCloskey
Secretary (Electronic Industries Association)

Ilene B. Jacobs
Treasurer (Digital Equipment Corporation)

Donald L. Hammond
Chair, Policy Committee (Hewlett Packard)

William D. Stotesbery
Vice Chair, Policy Committee (Westmark Systems, Inc.)

Donald J. Grace
Vice Chair, Policy Committee (Georgia Institute of Technology)

Dr. Joseph A. Saloom
Founding Chairman (M/A COM, Inc.)

Table of Contents

What is CORETECH?

The Council on Research and Technology, CORETECH, was established in early 1987 to develop and implement national public policies that encourage research and development and hence, U.S. competitiveness. CORETECH represents a broad cross-section of the American research community and has corporate, university, research institute, and association members.

CORETECH

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MAKING U. S. MATHEMATICS EDUCATION THE BEST IN THE WORLD:

THE ROLE OF THE FEDERAL AGENCIES

Summary of the Meeting

March 22, 1989

A Conference Sponsored by the

Mathematical Sciences Education Board
National Research Council

and the

Federal Interagency Committee on Education
U. S. Department of Education

at the
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, DC

SUMMARY

MAKING U. S. MATHEMATICS EDUCATION THE BEST IN THE WORLD

THE ROLE OF THE FEDERAL AGENCIES

INTRODUCTION

On March 22, 1989, a unique conference was convened at the National Academy of Sciences in Washington, D.C., by the Mathematical Sciences Education Board (MSEB) and the Federal Interagency Committee on Education (FICE).

The purpose of the Conference was to address the impact on federal agencies of our declining national status in mathematics. Although, in recent years, national educators, policymakers, community leaders and members of the business community have begun to address this issue, there has been little awareness of the effect of this situation on the ability of federal agencies to carry out their important governmental roles.

Each federal agency is dependent on a high quality workforce and competes within the government and with private industry for the members of a declining pool of mathematically competent workers. The Conference was designed to review the implications of the continuing decline in the mathematical and scientific pool, to define the special skills needed by federal agencies and to develop a plan for helping federal agencies improve the long-term ability of the federal government to have access to a pool of potential employees to help fill their future needs for mathematically competent personnel.

DELEGATE ASSEMBLY

The conference was opened by Dr. Frank Press, President of the National Academy of Sciences, who noted that the presence of representatives of thirty-two federal agencies (listed at the end of this Summary) showed an impressive federal government commitment to education. He noted the statements of President Bush to make education one of the priorities of his administration and to focus particularly on improvements in the teaching of mathematics and science. The National Academy of Sciences currently is involved in many projects which reflect this same priority, including hands-on science education projects with the Smithsonian Institution. The National Research Council, in establishing the Mathematical Sciences Education Board, also committed itself to a major role in the reform of mathematics education from elementary schools through graduate school. The MSEB is addressing changes needed in curriculum, teaching methods and testing, and will be a continuing force for durable improvements in mathematics education.

Dr. Milton Goldberg, Director of the Office of Research at the U. S. Department of Education, noted the need to change societal attitudes about mathematics. American students are not learning mathematics well enough for the U. S. to maintain a position of leadership. A Nation at Risk, published by the Department of Education in 1982, dramatically described our declining educational status, and although some

7. A serious barrier to improving mathematics education is the failure of the public to understand what mathematics is and what it can do. The public sees mathematics as a fixed body of arbitrary rules where every question has one exact answer, rather than a field that deals with relationships and patterns.

Everybody Counts is a public preface to the long-term plans to involve diverse publics in mathematics education reform, recognizing that reform cannot come without the informed support of the larger public. It will require years of responsible and objective discussions, the development and dissemination of models, public information campaigns, and a sustained effort leading toward success. It cannot be another "bandwagon" in which cynical teachers decide to wait out yet another reform effort.

A national consensus must develop on goals, standards and policy that will actively involve local school systems and will permit voluntary local implementation efforts, variations and options. The new **Curriculum and Evaluation Standards for School Mathematics**, developed by the National Council of Teachers of Mathematics, will help set these national expectations. In late 1989, MSEB also will release a document about expected curricular revision and organization by the year 2000.

MSEB will initiate a Year of National Dialogue on reform of mathematics education. This national debate is not intended to produce a single federal solution. This discussion will benefit from the participation of all the federal agencies in the process of improving the intellectual health of the workforce. It will require collaboration without consideration of turf; effective national leadership, but not control. Allies will be needed to work on mathematical reform from preschool through graduate school.

Shirley Frye, the President of the National Council of Teachers of Mathematics briefly explained the new NCTM Standards and shared a copy of the Executive Summary with each participant at the Conference. The goal of the Standards is to help students value mathematics, become confident in their ability to do math, become mathematics problem solvers, and learn to communicate and reason mathematically.

The mathematics skills needed today are not generally those studied in the traditional sequence. Technology has broadened the area in which mathematics is applied, made graphing and calculation much easier, changed the nature of problems important to mathematics and enlarged the methods used to investigate problems. Calculators and computers must become available to all students and students need to learn to use them to process information and investigate problems. The vision must be to change mathematics from preschool through higher education by setting higher standards and by having higher expectations that those goals are achievable for all children.

Dr. Bassam Shakhashiri, the Assistant Director for Science and Engineering Education of the National Science Foundation, addressed the dimension of the challenge before us. He noted that the situation is more critical than what we faced in the post sputnik era because our population has increased by 50 million people in the past 30 years. We have more students to teach and need more qualified teachers, yet societal institutions are sluggish in responding to a change of that magnitude. The system is not supplying the number of scientists that will be necessary to maintain our position in science, technology and a global economy.

U. S. citizens now live in an advanced scientific and technological society so that even non-specialists need to understand, for example, the difference between astronomy and astrology, benefit from the advances in the nutritional sciences, deal with population control, and understand the greenhouse effect and the depletion of the ozone layer.

The National Science Foundation is trying to promote the flow of talent into mathematics and science careers and to create a supporting environment for those who pursue these careers, but it also aims for a mathematically and scientifically literate population required by an effective democracy. International mathematics comparisons are embarrassing to us, yet we know that children in the United States are not less capable than those of other nations. We have the national capacity to deal with these issues. Do we have the national will to do so?

By the year 2000, the U.S. will have a shortfall of about 430,000 holders of B.S. degrees, and this will have tremendous consequences on our national economy, national defense capabilities, efforts in space, etc. There will also be a shortfall of 8000 PhD graduates in these fields.

Although four million entering high school students express an interest in careers in the natural sciences and engineering, the number drops from 750,000 in the sophomore year to 590,000 seniors. In college those numbers continue to slide to 340,000 as freshmen and only 200,000 earn such degrees. Only 61,000 go on to graduate school; 46,000 get a Masters degree and fewer than 10,000 a PhD. Clearly, the pipeline is not only leaking: a hemorrhage is happening. The problem is even greater when one looks at the demographics in the country and recognizes that among the nearly 10,000 PhDs, only 10 are Black Americans.

Attitudes about mathematics are formed long before the high school sophomore year, and that is why interest is growing in efforts with elementary school students. There is a tremendous loss of potential talent in most minority school populations, and when this fact is linked to the high dropout rates, it becomes increasingly difficult to develop a mathematically literate population. Our reason for reform must not be to beat the Japanese, but to ensure that we improve the ability of every member of society to participate in and contribute to informed national decisions.

High standards should not be viewed as "locking someone out" if we provide the means for the general population to achieve those levels. That is why the NSF supports the efforts of the Mathematical Sciences Education Board and the National Council of Teachers of Mathematics to do more than set the standards -- we must help students achieve these standards. The federal government sets standards in many fields and helps all concerned meet those standards; for example, the FDA checks and approves over-the-counter medicines; the FBI cooperates with state and local law enforcement agencies; the federal highway agencies control funds tied to state speed limits.

THE FACTS OF LIFE

CDF found a gap between male and female outlooks that widens as they grow older:

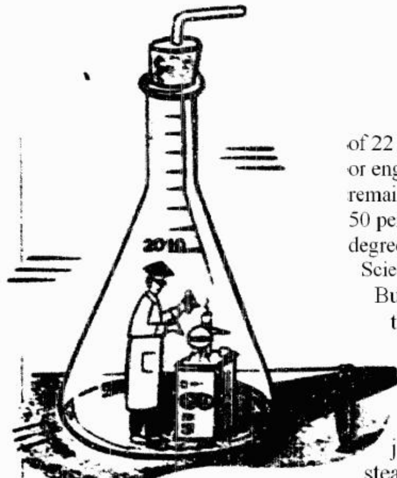
Teenage boys start having sex earlier than female teens. Almost half of males have had sex by age 16, compared to just over one-quarter of girls at that age, according to a 1987 National Research Council study.

A 1987 Search Institute survey also uncovered a divergence in how much teenage boys and girls talk and think about sex. By ninth grade more than half of all boys said they thought and talked about sex often and liked R- or even X-rated movies. Only about one-third of ninth-grade girls said yes to those questions.

The CDF concludes that sex education falls short when it fails to recognize such important differences. For teenage boys, their first sexual experience may be the primary symbol of manhood — a rite of passage — and changing this perspective is critical to reducing teen pregnancy. They recommend sex-education programs that emphasize responsibility and other routes to maturity, such as getting a job or a diploma. — E.S.

▼AMERICANS SPEND:
- **Five years of their life standing on line.**
- **Two years trying to return phone calls.**
- **Eight months opening direct mail.**
- **Six years eating.**
- **One year searching for misplaced objects.**
- **Four years on major household chores.**

Source: Michael Fortino, Priority Management



Scientist Shortage

In an era when researchers hope to develop an AIDS vaccine, teach computers to think like the human brain and fly astronauts to Mars, the demand for trained scientists and engineers is expected to increase over the next 20 years.

But at the rate college students are getting degrees in these fields, we may see a **scientist and engineer shortage estimated at a high 450,000 by the year 2010, according to Bassam Shakhashiri, an assistant director at the National Science Foundation.**

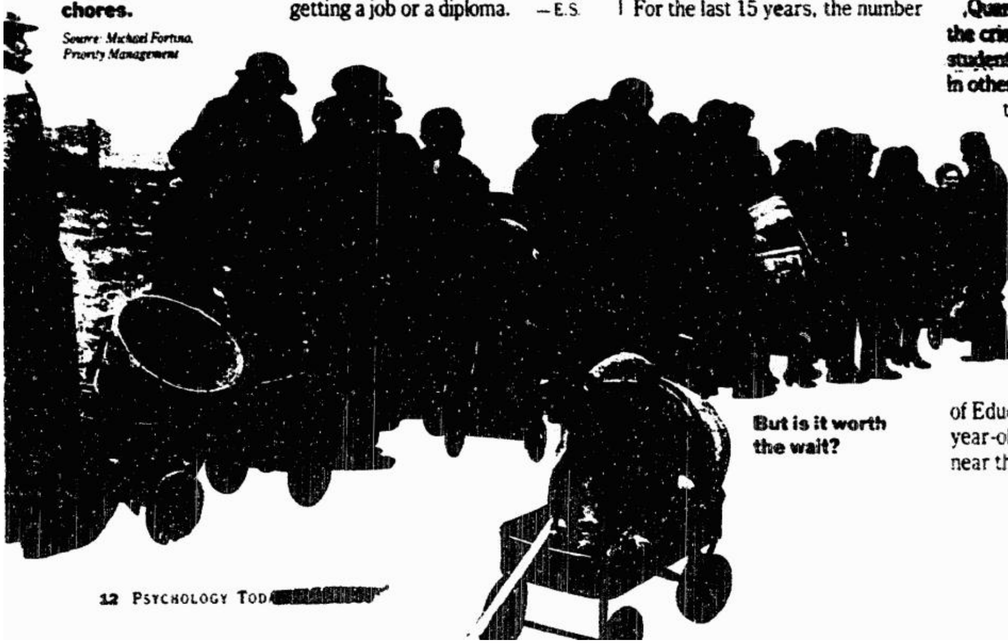
For the last 15 years, the number of 22 year-olds receiving science or engineering degrees has remained constant at about 40 to 50 per 1,000 undergraduate degrees, a National Academy of Sciences (NAS) study found.

But by the end of the century the number of people in that age group will drop by 25%. The degree attainment rate would have to rise to 65 per 1000 just to keep the supply steady.

This shortage could show up among science educators as well. More than one-third of today's college faculty is over 50, and many will retire in the next 10 to 15 years. But the rate at which natural science and engineering students have pursued doctoral work has declined by 50% since the mid-1960s, the NAS reports.

Cultivating an early interest in science may be the key to preventing a scientific shortfall. Currently, four out of five high school students are not interested in studying science by the 10th grade, the time when many of the basic science courses have already been taken.

Quantity may be only part of the crisis. Comparisons of U.S. students and their counterparts in other industrial nations reveal that our 9- and 17-year-olds lag behind in science and math achievement, Shakhashiri says. The latest International Assessment of Math and Science, an 11-country study conducted by the National Science Foundation and the U.S. Department of Education, found that our 13-year-olds finish last in math and near the bottom in science. — E.S.



But is it worth the wait?

AP/NEWS FEATURES

The Facts of Life Team: Mia Adessa.

Wanted: 675,000 Future Scientists and Engineers

A shortage of technically trained workers is looming, unless more women and minorities can be attracted to science

THE JOBS MARKET for researchers with freshly minted Ph.D.'s is tight right now, creating tough competition for those who want to advance in scientific and technical fields. But if the National Science Foundation's vision of the future is correct, the situation will soon reverse. A "sellers' market" will develop over the next decade, according to NSF, in which companies and universities will be falling all over each other to recruit young scientists and engineers to replace older employees who are coming up for retirement.

That will be good news for those now in the educational pipeline, but it could spell disaster for the U.S. economy. Even though better opportunities should lure able students into science, a shortfall of about half a million scientists and engineers is expected to develop by the end of the century. And this shortfall is looming at a time when overall educational standards in the United States are dismally low in comparison with those of America's major industrial competitors. Says William O. Baker of Bell Labs, the country can no longer operate on the old assumption that "the gifted and talented will see us through."

The crisis that is being widely predicted over the next decade is rooted in an incontrovertible demographic fact: because of low birthrates in the 1960s and 1970s, the college-age population—the raw material for tomorrow's educated workforce—is shrinking. According to the Census Bureau, numbers of 18- to 24-year-olds will bottom out at a little under 24 million in the mid-1990s—compared with a peak of over 30 million in 1980. Currently, a little over 5% of 22-year-old Americans earn B.S. degrees. Unless that fraction is increased, says NSF, there will be a shortage of 400,000 scientists and 275,000 engineers by 2006.

Although the dip in the college-age population will be temporary—the children of the baby boomers will be entering their early 20s in growing numbers in the late 1990s—the nation could still be faced with a shortage of scientific manpower over the long term because of growing proportions of nonwhites in the population. Current new additions to the workforce are mainly women, immigrants, blacks, and Hispanics, groups that have traditionally been grossly underrepresented in science and engineering.

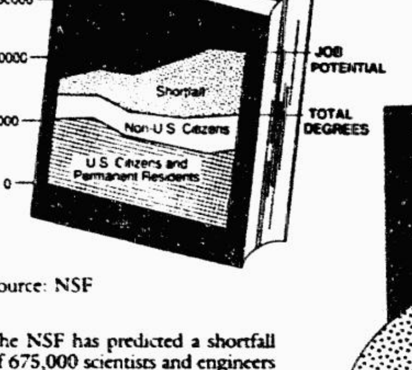
In fact, Jaime Oaxaca of Northrup Industries, a member of a congressionally established task force on women and minorities in science, says recent trends make the NSF's shortfall projections "look super-optimistic." Says Oaxaca: "The dilemma we face is by and large America doesn't believe there's a problem because America's a short-term thinker."

Others are more sanguine. Hilliard Williams, research director at Monsanto Corp., admits that a look at the demographic picture could easily persuade one that "we are headed for a period of immense crisis." But he believes that the fears are exaggerated and that market demand will draw in more people, particularly foreigners, to fill the gap. Aggressive recruitment of women and minorities is essential, he says, but as far as such programs are concerned, "I don't see much of anything having a profound effect in less than 10 years."

Engineer Mildred Dresselhaus of the Massachusetts Institute of Technology, who headed a National Academy of Sciences workshop on women in science and engineering, says that despite spot shortages, the manpower crunch is yet to be felt at higher degree levels. At the moment, she says, students fresh out of graduate school are actually encountering a constricted job market. Industry demand is "soft" because of slow growth in R&D expenditures and academic research funding is tight. But although she believes "demand and supply are pretty well matched now," she predicts "the tide will turn very rapidly" as the rate of retirements accelerates in academia.

On one point, all are agreed: If a long-term shortage of scientists and engineers is to be averted, unprecedented numbers of women and minorities will have to be attracted to technical careers. There are a few bright spots. Asian Americans, for example, are heavily invested in natural sciences and engineering; although they constitute only 2% of the population, in 1986 they garnered 5% of the doctorates in these fields. But overall, recent trends provide scant hope

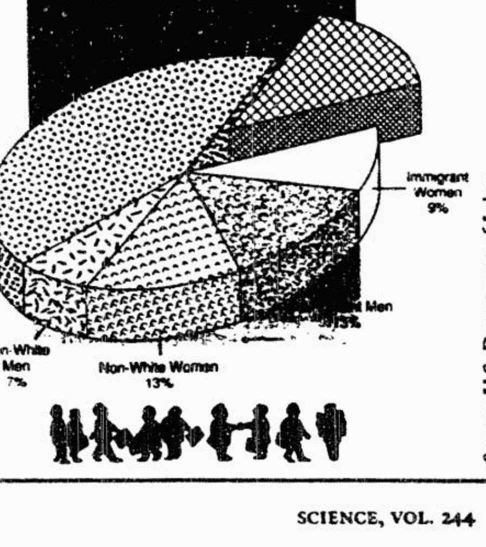
The Ph.D. Shortfall



Source: NSF

The NSF has predicted a shortfall of 675,000 scientists and engineers by 2006 as a result of the dip in the college-age population in the 1990s. This assumes that about 5% of 22-year-olds will get B.S. degrees and 5% of B.S. holders will obtain Ph.D.'s. A shortfall of some 9000 Ph.D.'s is anticipated by 2000, assuming the market causes a rise in salaries. The situation is aggravated by the accelerating pace of retirements from academia—by 2000, about one-third of the current faculty will have to be replaced.

White men now make up 47% of the total workforce and about 80% of the science and engineering workforce of 4.6 million. But they will constitute only 15% of the net number of 25 million people entering the workforce in the last 15 years of the century. By 2010, they will make up less than one-third of the college-age population.



Source: U.S. Department of Labor

that women and minorities will plug the projected gap.

The number of women planning careers in science and engineering appears to have plateaued after peaking in the late 1970s. Female participation in the science and engineering workforce has grown to about 15% from 13% a few years ago. The slowdown is not surprising: Women scientists still suffer higher unemployment, lower pay, and fewer opportunities for promotion at every degree level than do males. According to the Office of Technology Assessment (OTA), "the gender gap in recruitment to and participation in science, reduced by two decades of gains, is in danger of widening again."

Although women account for about one-third of all doctorates in the sciences, they tend to be concentrated in the social sciences and psychology. In fact, the number of Ph.D.'s awarded to women in natural and computer sciences has stayed flat since 1983. A similar pattern prevails at the undergraduate level, with some exceptions—for example, 38% of the freshman class at MIT is now female. The Educational Testing Service reports that only 11% of female SAT-takers, compared with 34% of the males, plan to study the physical sciences in college.

The situation for blacks and Hispanics is, unfortunately, even worse, because both groups continue to lag far behind whites from early elementary school onward. "The participation of blacks and Hispanics in engineering, as well as the physical sciences, shows little sign of substantial increase," says the OTA.

In some respects, the lot of blacks, particularly males, has actually been deteriorating. Blacks, now more than 12% of the population, make up about 2% of the science and engineering workforce. Although various reports claim that they now graduate from high school in roughly the same proportion as whites, the percentage of black high school graduates going on to college dropped from 33% to 26% in the decade ending in 1986. This mainly reflects the dramatic drop in black males going to college: black females on campus generally outnumber black males by two to one.

At the Ph.D. level, the situation is even bleaker. According to the National Research Council, the numbers of blacks earning Ph.D.'s in all fields has dropped by 27% in the past decade. More than half of all black Ph.D.'s are in education. In 1988, according to the NSF, the combined total of Ph.D.'s in the natural sciences and engineering for blacks and Hispanics was a mere 287.

Hispanics, who now make up perhaps 9% of the population, have the worst high school dropout rate of any group and, as with blacks, college enrollment has declined in the past decade. Moreover, only 25% of Hispanics who attend 4-year colleges persist to get their bachelor's degrees. Despite their smaller numbers, Hispanics are getting roughly the same percentages of higher degrees in the sciences as blacks.

Can the pull of market forces lure more women and minorities into scientific careers, as Monsanto's Williams hopes? Even he is discouraged that "the minority community doesn't realize what a gold mine of opportunity sits there today." Industrial competition for minorities and women "is absolutely fierce" and big companies are sometimes offering them higher salaries than white male competitors. But despite that, he says, "the hardest thing in the world to find is a Ph.D. female [or black or Hispanic] chemist."

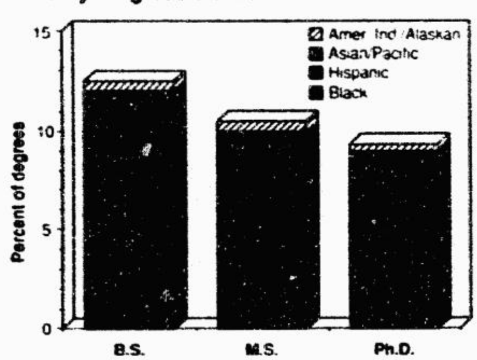
The NSF does not express all that much optimism that the market alone will be enough to fill the gap. Peter House of NSF says the greatest immediate payoff would be from efforts to improve the college retention rate of students who already have an expressed interest in science and engineering. In an April report on future scarcities of scientists and engineers, the NSF says the problem could also be remedied if the 8% of high school graduates who don't go on to higher education, but whose grades and course-taking qualify them as "apparently able," could be induced to go to college. Furthermore, the agency says increased scholarship support would provide quick results, especially at the Ph.D. level. Foreigners won't make up the shortfall, it says, unless there are "significant reductions in barriers to obtaining student visas."

There are enormous numbers of government-, university-, and industry-sponsored programs now operating at all levels of education that are designed to raise the participation of women and minorities in science. But the NSF report says that "it is too late for precollege programs to contribute" to alleviating looming Ph.D. shortages in science.

To NSF director Erich Bloch, it will take 20 years to bring about necessary improvements in precollege education. But even if schools eventually succeed in providing a solid early foundation for all students, there is no guarantee that blacks and Hispanics—or women—are going to gravitate in great numbers toward physics, math, computers, and engineering. Policy-makers seem to have adopted the implicit assumption that these groups should ultimately distribute themselves in the disciplinary patterns favored by white males. But it may be that as the demography of science shifts the landscape too will be altered.

■ **Constance Holden**

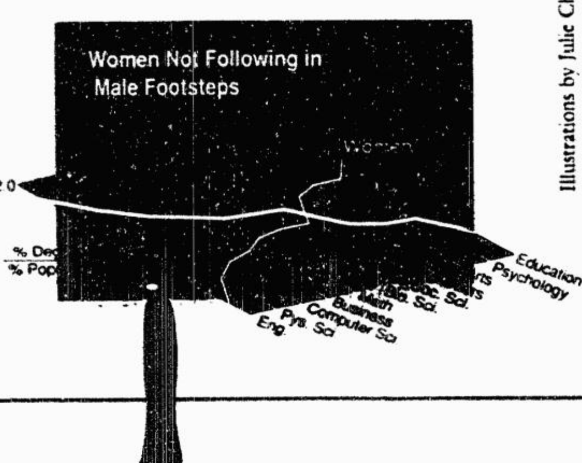
Minority Progress Stalled



Blacks, Hispanics, and American Indians continue to show high drop-out rates from high school and college, and college attendance has declined over the past decade. Blacks and hispanics make up more than 20% of the population but get only 7% of B.S. degrees and 4% of all science and engineering doctorates. In physical sciences, engineering, math, and computer sciences, proportions of black and Hispanic doctorates each hover in the neighborhood of 1%.

Source: *Educating Scientists and Engineers, Grade School to Grad School*, OTA, 1988

Women get almost 40% of B.S. degrees and have been making gains in graduate school. But female interest in engineering seems to have plateaued since 1983. Heavily represented in biology, health sciences, and psychology, they get only 16% of doctorates in the physical sciences, 10% in computer science, and 7% in engineering. Asian women are the only ones who violate the overall pattern: the highest number of B.S. degrees are in computer sciences, math, and biology.



Illustrations by Julie Cherry

EDUCATION

Science and Math Training Stirs Concern on Hill

Business, academic groups warn that U.S. is lagging, but budget squeeze keeps funding modest

Widespread concern over the sorry state of science and math education in the United States has prompted much hand-wringing in Congress over the years and some new federal programs, but relatively little money.

This year, with interest peaking yet again, the outcome probably will not be much different. The only proposals under active consideration are limited, largely symbolic and in some ways self-serving — a smattering of college scholarships, including, in one proposal, two for each congressional district.

"Those scholarships are nice, but it's not much; the problem is huge, and getting a few more scientists or a few more science teachers is not going to solve the problem," says E. James Rutherford, director of an American Association for the Advancement of Science (AAAS) project aimed at improving math and science education in the United States.

Responds Rep. Doug Walgren, D-Pa.: "Clearly, we're not saying, or even suggesting, that this bill is going to provide the support for the breadth of math and science training that this country is going to need. It is, I think, an important symbol. . . . We are trying to set an example." Walgren is the sponsor of HR 996, which includes the two-per-district scholarship proposal approved by the Science Committee July 27. *(Weekly Report p 1970)*

In the age of the budget deficit, Capitol Hill's response to the math and science education problem is not unique. The plagues of drugs, homelessness, pollution, and inadequate access to health care all produce loud calls for action, some new programs and not much money. Pitted against those societal ills and others, science and math education isn't likely to top the nation's agenda any time soon.

By Phil Kuntz

AMERICAN ASSOCIATION OF SCHOOL ADMINISTRATORS

Science groups say not enough students are pursuing math and science at all levels of education.

The issue, however, provides an interesting look at one of the nation's lesser-known problems — a crisis waiting to happen, some experts say.

The Challenge

Hardly anyone disagrees that there is a problem.

"The harsh truth is that science and mathematics education in the United States is in bad shape," says Ernest L. Boyer, president of the Carnegie Foundation for the Advancement of Teaching.

The nation's schools — already battered for failing to teach their charges to read and write — are turning out what experts call "technologically illiterate" students. Many teachers are considered unqualified to teach their subjects. Some experts are predicting massive shortages of scientists and engineers as the 21st century dawns *(Graphs, pp 2181, 2183)*

Such concerns are heightened by the United States' tenuous position in the world's increasingly international marketplace. While still a dominant economy, the country suffers from a massive trade deficit, exacerbated by fierce competition from high-tech companies in Japan and elsewhere.

"What are our prospects for success in capturing our share of foreign trade in the 21st century if our schools are not preparing a technologically literate work force today?" asks House Science Chairman Robert A. Roe, D-N.J. He says the quality of science and math education "will largely determine the future economic strength of our nation."

Bassam Z. Shakhashiri, chief of the National Science Foundation's (NSF) education programs, dramatically reminds listeners of the national panic that followed the Soviet Union's launching of the Sputnik satellites in the late 1950s. Thereafter, education spending by the NSF skyrocketed. *(NSF education spending graphs, pp 2180, 2182)*

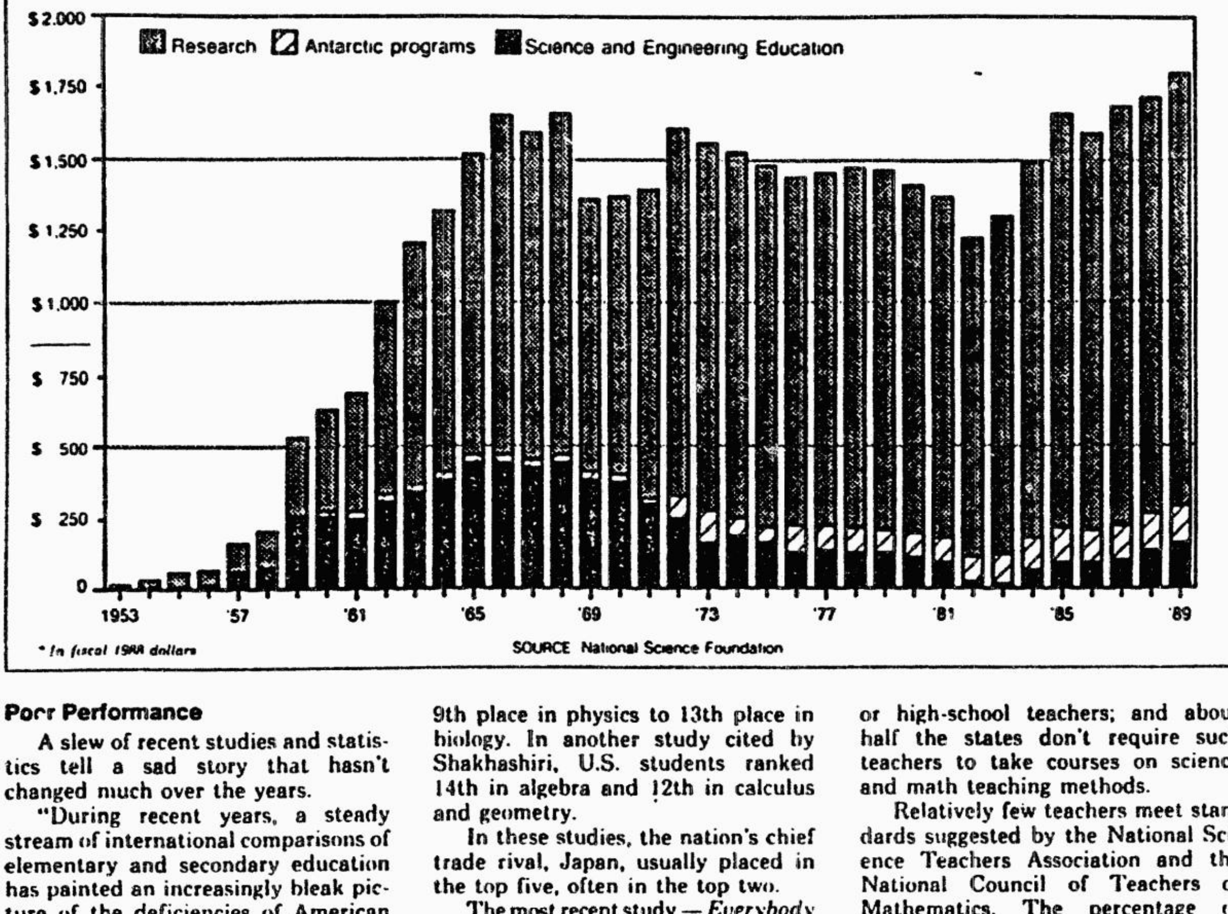
"We need to develop a national will, a national determination," says Shakhashiri. "We did a lot of good in the '60s, when the nation was mobilized after Sputnik. We had a national determination, a national will to pursue those goals. We perceived Sputnik as a military threat. What we have now is an economic threat, but its effect is not felt as quickly as a satellite circling the Earth every hour or so."

The trick, he concedes, is convincing the nation that today's threat is just as dangerous.

29

National Science Foundation Spending

(In millions of dollars)*



* *In fiscal 1988 dollars*

SOURCE National Science Foundation

Poor Performance

A slew of recent studies and statistics tell a sad story that hasn't changed much over the years.

"During recent years, a steady stream of international comparisons of elementary and secondary education has painted an increasingly bleak picture of the deficiencies of American mathematics and science education," says a 1988 report from Congress' Office of Technology Assessment (OTA).

In such studies, American students generally score, in the words of Sen. John Glenn, D-Ohio, the former astronaut, "embarrassingly low." The NSF's Shakhashiri says the United States' performance in one such study ranged "from poor to shameful."

In a recent speech to a group of mathematicians, Shakhashiri rattled off distressing figures from a 1988 study by the International Association for the Evaluation of Educational Achievement:

U.S. fifth graders ranked eighth in science achievement, while ninth graders fared worse — 15th place, ahead of only Hong Kong. Even those high school seniors considered serious about science did poorly, ranging from 9th place in physics to 13th place in biology. In another study cited by Shakhashiri, U.S. students ranked 14th in algebra and 12th in calculus and geometry.

In these studies, the nation's chief trade rival, Japan, usually placed in the top five, often in the top two.

The most recent study — *Everybody Counts*, a National Research Council report representing a consensus of 70 science, math and education groups — concluded in January that most students leave school ill-prepared mathematically to perform most jobs.

Behind poor student performance is an army of underqualified teachers. "Few elementary-school teachers have even a rudimentary education in science and mathematics, and many junior and senior high-school teachers of science and mathematics do not meet reasonable standards of preparation in those fields," says *Science for All Americans*, a report by the AAAS.

According to an NSF summary of studies of science and math teachers, many states have no science and math course credit requirements for elementary-school teachers; 31 states have no such requirements for middle- or high-school teachers; and about half the states don't require such teachers to take courses on science and math teaching methods.

Relatively few teachers meet standards suggested by the National Science Teachers Association and the National Council of Teachers of Mathematics. The percentage of teachers meeting the standards range from 34 percent for elementary-school science teachers to 10 percent for middle-school math teachers, according to the NSF summary.

In addition, such teachers are overworked and use ineffective textbooks, methods and curricula that dwell on memorization of "needless detail" instead of teaching students how to think scientifically, the AAAS report says.

Coming Shortages?

These deficiencies may exacerbate the underlying fear of those concerned about science and math education. Although current indicators suggest that the nation has enough scientists and engineers now, some say shortages loom in the coming decade or so.

[illegible]," says the NSF's [illegible] going to have a tremendous shortfall."

Driving the shortage predictions are simple demographics. The college-age population is dropping as the baby-boom generation grows older. That means a shrinking pool of potential scientists and engineers. While the overall pool shrinks, the population of minorities will grow, meaning that any effort to reduce the shortfall will have to include recruiting more blacks and Hispanics, who traditionally have been underrepresented in science and math fields. Likewise, women would have to be more aggressively recruited.

The demographic realities emerge at a time when fewer college students are majoring in science and engineering. The American Council on Education says that between 1977 and 1987, there were significant drops in the percentage of freshmen choosing various science and engineering majors.

[illegible] demographics and slipping [illegible] will likely be felt [illegible] the 1990s. In other words, demand will [illegible] supply.

"This imbalance will have devastating consequences," says Richard C. Atkinson, chancellor of the University of California and president of the AAAS.

Estimating the size of the shortage is a tricky business, for it involves making chancy projections about demand.

Nevertheless, the AAAS estimated in a report released Feb. 16 that the nation will need about 18,000 new natural science and engineering Ph.D.-holders per year in the early part of the 21st century, but will be producing only about 10,500. Figures from the NSF predict a cumulative shortfall of 103,000 between now and 2006. Lower on the educational ladder, at the B.S.-degree level, the NSF predicts an even bigger cumulative shortfall: 765,000, and that's assuming that demand stays flat.

"Steps to deal with the shortfall should have been taken years ago," says the AAAS's Atkinson of the Ph.D. shortage. "Since we are starting late, our efforts will have to be even more vigorous." The AAAS has suggested that the government spend $300 million annually on 3,000 new Ph.D. fellowships each year.

Blown Out of Proportion?

There are some in the science community who think the supply problem has been blown out of proportion. The OTA caused a bit of a stir last year when its report on the subject said: "OTA concludes that [illegible] and engineers are [illegible]

[illegible] the labor market will continue to adjust, albeit with transitory and perhaps costly shortages and surpluses."

"Some folks ... have implied that we're saying there's nothing to worry about, and that's not what we're saying," says OTA Assistant Director John P. Andelin Jr. "[illegible]."

But [illegible] president of the science teachers group, says, "I'm not convinced." The labor market will adjust by forcing salaries up, attracting more students to pursue careers in science, he adds.

Shamos wrote a piece last year titled "A False Alarm in Science Education" for the magazine *Issues in Science and Technology*. He argued that the "crisis" was trumped up by the science community to fight the Reagan administration's decision in the early 1980s to dismantle the NSF's Directorate for Science and Engineering Education, a move rejected by Congress.

"It was no coincidence that a 'crisis' was declared at the same time as federal support for science education dried up," Shamos wrote. He is working on a book, "The Myth of Scientific Literacy," in which he says he will argue that making all students scientifically literate "is an impossible goal."

Who's Spending What?

A host of federal agencies spend money on science and math education, although no effort has been made to determine exactly how much is spent each year. "My instinct is that the programs scattered around the government are not that visible," says Rep. Walgren.

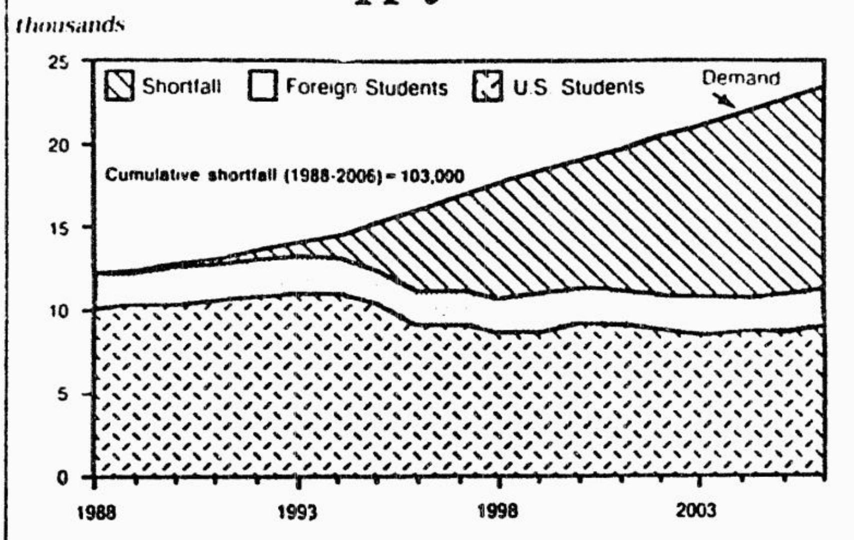
The OTA identified more than 100 programs in a dozen different agencies. Most are quite limited, with 1988 spending ranging from less than $100,000 to several million dollars. Many of the more expensive ones — research-grant programs, for example — have a broader purpose than improving science education or increasing the nation's supply of scientists.

The two main programs aimed specifically at improving science and math education are those run by Shakhashiri at the NSF's Science and Engineering Education Directorate and the Department of Education's Dwight D. Eisenhower Mathematics and Science Education program.

The NSF directorate awards grant money at both the college and precollege levels for researching and developing new instructional materials and methods and for teacher improvement. It also provides money for graduate fellowships to encourage students to enter math and science fields.

Congress [illegible] $190 million [illegible] The House-passed HUD-VA-Independent Agencies appropriations bill (HR 2916 — H

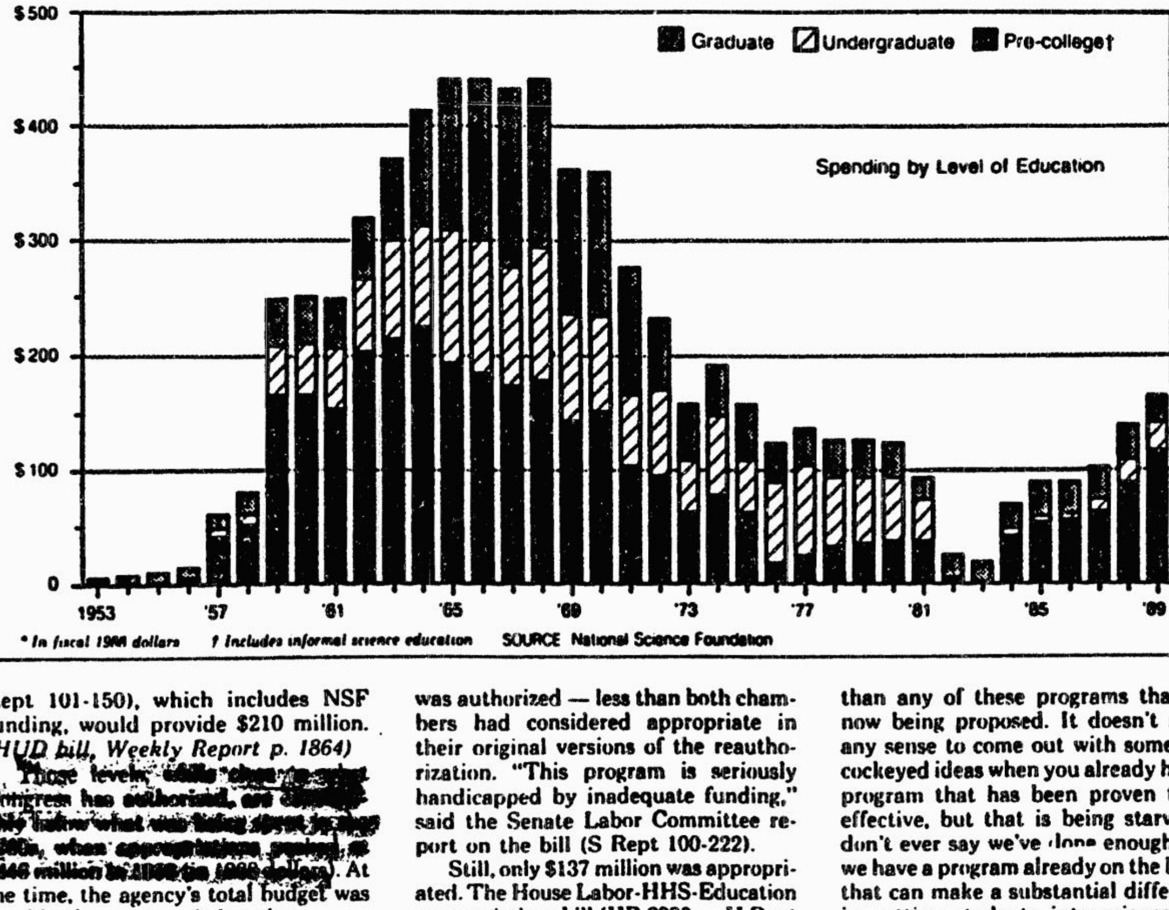
Science and Engineering Ph.D.s Future Supply and Demand



SOURCE: National Science Foundation

NSF Science and Engineering Education

(In millions of dollars)*



* In fiscal 1988 dollars † Includes informal science education SOURCE: National Science Foundation

Rept 101-150), which includes NSF funding, would provide $210 million. *(HUD bill, Weekly Report p. 1864)*

[redacted]. At the time, the agency's total budget was roughly the same as it is today.

Nevertheless, the directorate has rebounded considerably since the Reagan administration cut NSF's education budget to just $19 million, preferring to focus NSF spending on research programs. For his part, Shakhashiri says he would like to see spending hit $600 million by 1994.

The Education Department's program was first authorized in fiscal 1984 with passage of the Education for Economic Security Act (PL 98-377), which provides grant money to state and local governments to improve math and science education programs.

It called for close to $1 billion in new spending in its first two years, but only $400 million was actually appropriated.

In fiscal 1989, when the program was reauthorized and renamed after President Eisenhower, $250 million was authorized — less than both chambers had considered appropriate in their original versions of the reauthorization. "This program is seriously handicapped by inadequate funding," said the Senate Labor Committee report on the bill (S Rept 100-222).

Still, only $137 million was appropriated. The House Labor-HHS-Education appropriations bill (HR 2990 — H Rept 101-172) for fiscal 1990 cuts the program's budget to $100 million. The reason, according to the Appropriations Committee report: The NSF's program is more effective, because the Department of Education grants are spread around the country too thinly.

No Appetite for More

Because the programs they helped create are not being fully funded, House Education and Labor Committee members don't have much taste for new programs.

"The problem stays, but the attempt at a solution is forgotten," laments Pat Williams, D-Mont.

Committee Chairman Augustus F. Hawkins, D-Calif., says the program his committee helped craft should be fully funded: "We think that would do more than any of these programs that are now being proposed. It doesn't make any sense to come out with some new cockeyed ideas when you already have a program that has been proven to be effective, but that is being starved. I don't ever say we've done enough, but we have a program already on the books that can make a substantial difference in getting students into science and math and encouraging teachers to become proficient in those fields. All it needs is money."

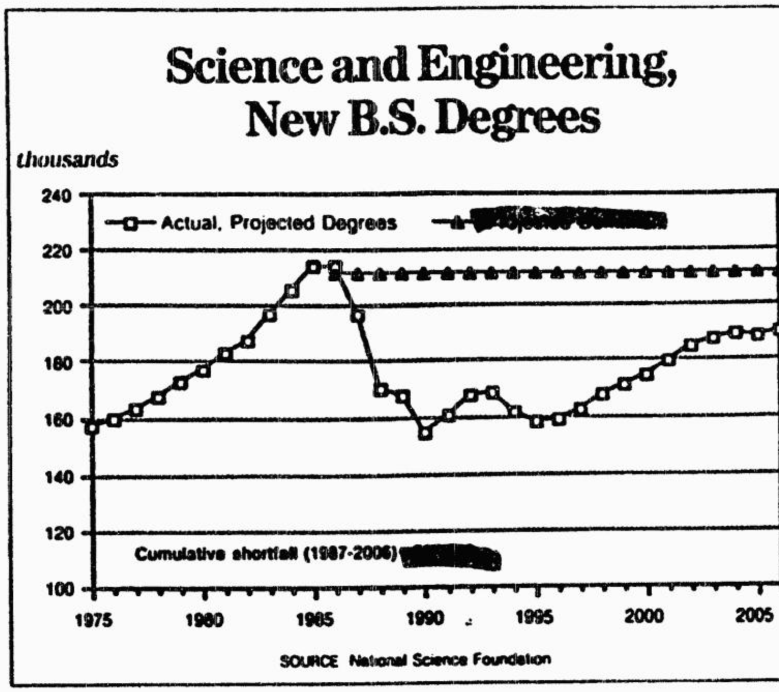
Hence, he says his committee plans no big initiatives this year. Williams says the committee may include something limited to increase the supply of science teachers — perhaps forgiving student loans for those agreeing to teach science for a time — if it drafts a response to the national and community service package (S 1430) now ready for Senate floor action. *(National service, Weekly Report p. 2050)*

The House committee's Senate counterpart, Labor and Human Resources, has approved a package (S 695) of President Bush's education proposals that includes some science scholarships. Similar to Walgren's proposal and its Senate companion (S

134), which was sponsored by Glenn, the bill would provide four-year, $20,000 scholarships for one male and one female science or math whiz in every congressional district. Hawkins has balked at the president's education proposals, but there's a good chance he will accept some version of them by the end of the Congress.

"You're not talking about anything that is fundamentally going to make a difference," says an aide to Senate Labor Committee Chairman Edward M. Kennedy, D-Mass., of scholarship proposals. But it can't hurt: "The federal government can raise the visibility of the issue. This is the bully pulpit role of the federal government."

Kennedy plans sometime in the 101st Congress, perhaps not until next year, to move a bill aimed at improving the quality of all teachers. That bill may include something aimed specifically at science and math teachers, his aide says.



House Science Panel Plan

The committee most active on the issue this year has been the House Science, Space and Technology Committee. It approved a $32 million per year package (HR 996 — H Rept 101-220) of proposals using NSF-administered scholarships to encourage students to pursue math and science careers. The proposals were offered by three Science Committee members:

- Walgren. Under his proposal, originally introduced last year, one boy and one girl from each congressional district would receive a four-year, $20,000 scholarship to major in science, math or engineering. If they switched majors, they would have to pay the money back as if it were a student loan.

[redacted] College junior and senior science and math majors would be eligible for $7,500 a year for up to three years. They would have to promise to teach for up to four years; if they don't, they would have to pay the government back, plus interest.

- D. French Slaughter Jr., R-Va. His section of the bill (originally HR 1217) would provide another 500 scholarships to undergraduates who promise either to work for two years for the government or private sector as a scientist or engineer, or to go on to graduate school for two years in science, math or engineering. Recipients each would get up to $12,500 in government money over up to three years. Those who fail to complete the service requirement also would have to pay the government back.

Drawbacks to Bill

While many in the science community have welcomed the bill, some say it does have its deficiencies.

It would do little to draw minorities into science fields. Because the committee wanted scholarship awards to be merit-based, it would allow financial need or minority status to be taken into account only when the NSF is "making final selection of awards among individuals of essentially equivalent merit."

And the bill is aimed at rewarding the best science and math students, so it probably won't do much to improve the quality of the large majority of American students — the ones who do poorly in international comparisons.

For the same reason, some say its ability to draw people into science who would not have entered the field anyway is also probably limited. And even if every scholarship went to someone who otherwise would have entered another occupation, only 1,870 science and engineering workers a year would be added to the labor force — far short of the size of the shortfall predicted by experts.

Some members supporting the bill also quietly agree that its two-per-district requirement is a self-serving provision aimed at producing publicity for incumbents. Walgren, however, denies such intentions. He notes that members would have nothing to do with choosing who gets the scholarships. He defends a provision requiring members to be notified of scholarship selections in their district before they are publicly announced. The provision, Walgren says, is designed to allow members to make the announcements first, so the awards get maximum local attention and other students are encouraged to study science.

"We want as much publicity in terms of recognition of these awards as possible," Walgren says. "That's a plus."

As of now, it looks like some sort of science scholarship will be enacted by the 101st Congress, but no one says that will be the end of Capitol Hill's interest in science and math education. "Science education is a perennial issue with the Congress," says the NSF's senior legislative analyst, Joel Widder. "The level of interest goes up and down. This year, it's at a high peak."

But that's not because the situation has deteriorated, he adds: "The numbers are just as distressing as they have always been." ■

People Needs: Work Trends And Shortages

WITHIN AN ENVIRONMENT of growth and technological advances, aerospace professionals will have to wield the right skills to command the best jobs and salaries.

Overall, the aerospace industry is most concerned about a shortage of engineers during the next decade.

[redacted]

This shortfall will be exacerbated because a large percentage of those graduating in the next decade will be immigrants whose clearance to work on defense projects will be difficult. Moreover, non-U.S. citizens overwhelmingly dominate the pool of graduates with advanced degrees in science and engineering.

The predicted shortage of engineers will come at a time when new technology development begs for greater numbers of engineers. "TRW's Space & Technology Group plans a 20% increase in engineers by the year 2000," Tom McDonald, director of human relations, said.

Texas Instruments foresees shortages of engineers in the 1990s, according to Steve Leven, vice president of personnel for the Defense Systems & Electronics Group. As a result, "engineering salaries will be very competitive in the 1990s," he said.

Many companies, such as Hercules Aerospace Co., anticipate block retirements of engineers hired in the 1960s and 1970s. This large group of post-Sputnik scientists, the gray beards of the industry, will take a lot of knowledge and experience with them.

"The Avionics Group of Rockwell International is concerned about recruiting software engineers in the 1990s," Tony Huebsch, director of communications, said. "There is a new relationship now where engineers must understand both hardware and software. We used to need great numbers of hardware engineers, but now we need just as many software engineers."

"Large systems software engineers are critical to the future success of Hughes Aircraft Co.," Bill Smiley, manager of advanced manufacturing technology, said.

Cornell predicts a shortage of 560,000 engineering graduates by the year 2010.

A TRW engineer inspects a module that will be used in future avionics systems. Electronics and software engineers will be in short supply in the 1990s.

Electro-optics is a technology that will need engineers.

According to one expert, the Defense Dept requires 20 to 25 million lines of Ada code to develop the Advanced Tactical Fighter, the space station and the FAA's Advanced Automation System. Writing Ada software at the current rate of 2,000 to 3,000 lines per year means that 7,000 programmer years are required just for those three major projects.

[redacted] than 1% of students enrolled in coll last fall chose computer science as th major. In addition, there are few softw engineering undergraduate deg programs offered.

"The decision-makers who sho be working to solve this problem w educated in the 1950s and 1960s. T do not appreciate how critical the nee for software experts," Ralph Cra president of the consulting firm Softw Strategies and Tactics and editor of A Strategies Newsletter, said. "So companies think that hiring a m major and giving him or her 40 hr training will create a software engin Futuristic managers think they will bailed out by a technolog breakthrough and won't n knowledgeable people."

Grumman Corp., aware of shortage of software engineers, wo like its software experts to design a m system that can then be adapted to o engineers' needs using the experts' to "The people with unique skills must on top of this art," Chris Witt, direc corporate development laboratories, sa

Other types of engineers will als in short supply. Betty Vetter, execu director of the Commission Professionals in Science and Technol said there will be a severe shortage Ph.D.s by the year 2000. In order to personnel with advanced degrees, def contractors will compete with each o and will rob academia.

Aerojet ElectroSystems also ha difficult time finding microwave a millimeter-wave electronics speciali "There are only a few mid-le experienced people around and it is h to locate and attract them," Dean Roche, manager of employment, said.

TRW's McDonald added t electro-optics is a technology that need engineers. "We could use all electro-optic Ph.D.s with U.S. citize produced each year because so schools offer the degree and so students are in the program," he said.

"Not only will all disciplines engineers be in demand in the decade, but The Boeing Co. will

Dec 1989

THE WASHINGTON POST (Tuesday, December 19, 1989) p. A-6

Study Sees Shortfall of Graduates in Technical Skills

Task Force Recommends Efforts to Recruit Women and Minorities in Science, Engineering

By Kenneth J. Cooper
Washington Post Staff Writer

To meet labor market demands for technical skills in the next century, a congressionally chartered panel estimates that the nation's colleges must graduate twice as many white women in science and engineering, five times as many black students and seven times as many Hispanics—beginning next year.

The panel, established by Congress in 1986, arrived at the estimates by combining projections from the National Science Foundation, which foresees a shortfall of 560,000 scientists and engineers in the year 2010, and the Bureau of Labor Statistics, which projects that 85 percent of new workers in the year 2000 will be women or minorities.

"These numbers are real in the sense that all of these people who will be entering the work force are already born," said Sue Kemnitzer, executive director of the Task Force on Women, Minorities and the Handicapped in Science and Technology. The panel of 48 government, business and education leaders issued its final report yesterday.

The panel said the projected increases in undergraduate degrees in engineering and science must be achieved in every year of the 1990s, a goal that Kemnitzer acknowledged would be impossible to reach next year. "That is one point we're trying to get across—how dramatic the changes have to be," she said.

The panel's projected demand for women and minorities with doctoral degrees in science and engineering are even higher: three times as many white women, 12 times as many Hispanics and 20 times as many blacks. Last year, for instance, only 47 black Americans received doctorates in science and 15 in engineering.

No estimates were made concerning handicapped students because no statistics are collected on the types of degrees they receive.

In its long list of recommendations, which were endorsed by the White House Office of Science and Technology Policy, the panel proposed that:

- Colleges "set quantitative goals for recruiting and graduating more students in science and engineering, especially from underrepresented groups." But the panel, Kemnitzer said, rejected specific quotas for each group.
- The federal government provide college scholarships and research experiences to high school students who want to pursue science and engineering, particularly to women, minorities and handicapped students. President Bush has proposed funding two such scholarships in each congressional district.
- Local school districts station a math and science expert in each elementary school and emphasize scientific careers as "the best way 'up' for students from disadvantaged backgrounds." Currently, most elementary teachers do not specialize and provide instruction in every academic subject.
- Private industry fund training programs to improve the math and science knowledge of teachers, including sponsoring trips to national meetings of math and science teachers.

SRS-D5

ENGINEER AT LARGE

Demand to exceed supply for engineers

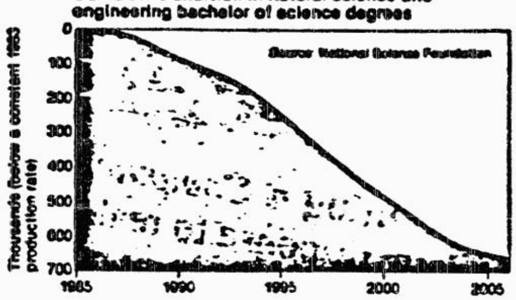
[redacted]

The NSF [redacted]port, "Future Scarcities of Scientists and Engineers: Problems and Solutions," says the reasons are demographic. The number of young adults is expected to decline over the next 16 years, yet the percentage of 22-year-olds receiving bachelor degrees in engineering and the natural sciences is likely to remain at 4 or 5 percent, as it has done for 30 years.

Entry of more women into these fields will apparently not help overall. Though the percentage of women with bachelors' degrees in engineering and the sciences has risen in the last three decades—from less than 1 percent of 22-year-old women in 1959 to 2.5 percent in 1986—the trend has been offset by a decline in the number of men receiving these degrees, from 7 to 6 percent, and that downturn is expected to continue. The addition of non-U.S. students at U.S. colleges will not help unless barriers to giving them student visas are dropped.

[redacted]

Cumulative shortfall in natural science and engineering bachelor of science degrees



and the number of bachelor of science degrees produced in these fields.

[redacted], to involve more [redacted]ties and women in similar pursuits, and to retain students through scholarship programs, the report advises. But, the NSF notes, implementing any strategy to address these problems is complicated by the necessity of coordinating activities of the responsible groups—from Federal agencies to local school boards.

Rewards for hard work

Merit pay increases for hardware engineers averaged 6.4 percent during the first half of 1989 and 5.9 percent for software engineers, according to the American Electronics Association's (AEA's) "Professional Engineers Salary Survey." Average monthly salaries for these nonsupervisory engineers were $2319 on the low end, $2628 on the high.

In the same survey, which was distributed to 70 605 engineers at 1124 companies, the AEA also found that U.S. electronics companies encountered a 12.72 percent average turnover rate of engineers in 1988, as opposed to a 10.01 percent average in 1987. Hardware engineers experienced a 10.25 percent average turnover rate.

Coordinator: Gary Stix
Consultant: Mary Golladay, National Science Foundation

The Washington Post ... Tuesday, January 9, 1990 A17

THE FEDERAL PAGE

Agencies Aim to Inspire Interest in Technical Careers

By Kenneth J. Cooper
Washington Post Staff Writer

Responding to orders from President Bush and recommendations from a congressionally chartered panel, federal agencies engaged in research and development are expanding their education programs in an effort to interest more students in science and engineering careers.

Agencies ranging from the Agriculture Department to the National Aeronautics and Space Administration have for years supported various education programs that touch students and teachers from the elementary to the postgraduate level. These programs provide student internships, college scholarships, teacher training sessions and model courses.

This year, the educational programs of just eight research agencies are expected to cost more than $9.3 billion—which is equivalent to about 40 percent of the Education Department's budget—according to the Task Force on Women, Minorities and the Handicapped in Science and Technology.

[redacted] recommendations focus on minorities, white women and the handicapped because they are expected to constitute 85 percent of new workers in the year 2000.

The 15 federal agencies represented on the panel have plans in varying stages of development to increase their educational activities. "Never before have the heads of these agencies focused on these commitments in this way," Sue Kemnitzer, the panel's executive director, said.

A spokesman for Education Secretary Lauro F. Cavazos said he is not territorial about the education initiatives at other departments and agencies. "The secretary welcomes any help he can get from the Cabinet," Mahlon Anderson, Cavazos's spokesman, said.

TRAINING SCIENTISTS AND ENGINEERS

FISCAL 1990 FUNDING BY SELECTED FEDERAL RESEARCH AND DEVELOPMENT AGENCIES FOR SCIENCE AND ENGINEERING EDUCATION (SHOWN IN MILLIONS OF DOLLARS)

	Funding for Minorities and Women	Funding for Everyone
Precollege, total	$11.3	$138.8
Curriculum	0.2	21.8
Teacher training	-	75.0
Students	3.4	14.5
General	7.7	27.5
[illegible]	[illegible]	[illegible]
Undergraduate, total	$43.8	$142.3
Curriculum	1.0	16.1
Faculty	0.7	10.0
Student support	30.0	32.0
General	12.1	84.2
[illegible]	[illegible]	[illegible]
Student support	[illegible]	[illegible]
General	[illegible]	[illegible]
Research, total	$137.5	536.5
Postdoctoral	3.7	380.9
Faculty	56.1	6,723.1
Institutional development	38.1	311.5
General	41.6	1,110.0
Total, all programs	[illegible]	[illegible]

NOTE: Shows estimated amounts for departments of [illegible] Energy, Interior, Environmental Protection Agency, NASA, National [illegible] Science Foundation. Figures do not include all education efforts [illegible] federal agencies.

SOURCE: Task Force on Women, Minorities and the H[illegible] and Technology

THE WASHINGTON POST

Bush has instructed his Cabinet to get involved with education in general and sought to demonstrate such a government-wide commitment by bringing all of the Cabinet to his education summit with the nation's governors last fall.

The research agencies have more than symbolic self-interest in trying to inspire more students to pursue technical careers: They could face personnel problems of their own if there are too few scientists and engineers. Those professions, for instance, represent more than half of the civil service employees at NASA. And 13 percent of federal workers are scientists or engineers, making the government the biggest employer of them in the country.

The research agencies also have the resources—scientists and laboratories—thought to be most useful in interesting youngsters in science and technology.

"That's why these federal R&D agencies with the labs are so important. They actually have the scientists who can help the kids in the labs and be role models and mentors," said Kemnitzer, who is on loan from the National Science Foundation.

Bonnie Brunkhorst, president-elect of the National Science Teachers Association, said the research agencies' efforts have "a lot of potential" and present "an excellent opportunity for role-modeling."

The most ambitious expansions have been proposed by the Energy Department and NASA.

The space agency has proposed increasing its education budget by $70 million, or 18 percent, to $469.8 million this year. The Energy Department has discussed initiatives that could cost $29 million or more. Neither agency has made final budget decisions.

NASA has developed a long-range plan to produce 320 minority graduates with doctoral degrees in science or engineering each year beginning in 2000. In that year, the total cost would be $132 million—with NASA and private industry each contributing a third and other federal agencies contributing the rest. NASA estimates most of its funding would come from existing programs.

To reach its goal, NASA would increase from 500 to 1,500 the number of minority students working at NASA installations or college laboratories during the summer while in high school. "When we pick up these students at the high school level, we want to start thinking PhD at that point," explained Robert Brown, director of education programs at NASA.

The students would flow into NASA's work-study and fellowship programs once they reach college and graduate school. The space agency projects 60 percent will receive at least a masters degree.

At the Energy Department, Secretary James D. Watkins, whose biggest concerns are nuclear weapons production and nuclear waste storage, last October hosted a national conference in California on math and science education.

The most ambitious proposal Watkins discussed there would have department scientists participate in upgrading the math and science skills of all precollegiate teachers by the year 2000. The first group of teachers, 10 percent of them, would receive training in the 1990-91 academic year. Watkins did not estimate what it would cost to train more than 2 million teachers who instruct students in grades kindergarten through 12, although the cost would be substantial.

Brunkhorst, a professor of geology and science education at California State University-San Bernardino, called the Watkins proposal "marvelously naive," because of the potentially high cost. While praising Watkins for his interest, she said that any training should be done in conjunction with experienced educators and not solely by Energy Department scientists.

Watkins has also moved to broaden the involvement of department labs in education. He has

This year, the educational programs of just eight research agencies are expected to cost more than $9.3 billion.

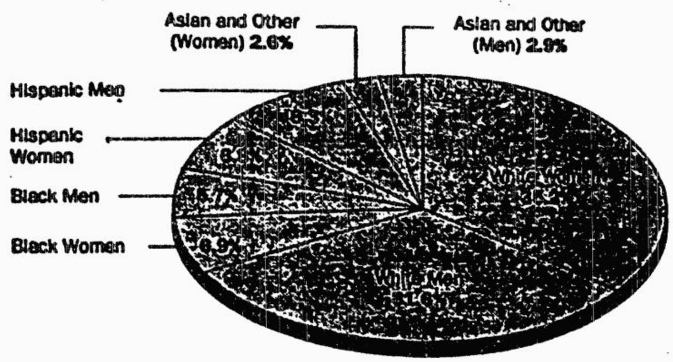
committed $532,000 to a "science explorers" program linking Chicago's public schools to the nearby Argonne National Laboratory and Fermi National Accelerator Laboratory. Another new program links Oak Ridge National Laboratory and the University of Tennessee to provide alternative teaching certificates to scientists and engineers as well as train new math or science teachers.

Other agencies planning to expand education efforts are: the Agriculture Department, the Commerce Department, the Defense Department, the Environmental Protection Agency, the Federal Emergency Management Agency, the Department of Health and Human Services, the Department of Housing and Urban Development, the Interior Department, the Labor Department, the National Science Foundation, the Office of Personnel Management and the Transportation Department.

THE CHANGING WORK FORCE

The nation's pool of talent for new scientists and engineers by the end of the century will be predominantly female, minority or disabled—the very segments of our population the nation has not attracted to science and engineering careers in the past.

An estimated 42.8 million persons will enter the overall labor force between 1988 and the year 2000. The breakdown:



Source: Bureau of Labor Statistics' Task Force on Women, Minorities and the Handicapped in Science and Technology.

Los Angeles Times

Goals Proving Elusive for Science Education

■ **Funding:** The many conflicting ideas on how to revamp the system are only adding to the growing crisis.

By EDWIN CHEN
TIMES STAFF WRITER

WASHINGTON—In setting ambitious achievement goals for science education, President Bush in his State of the Union address Wednesday night spotlighted one of the nation's most thoroughly documented problems. The abysmal state of science education has been chronicled by more than 300 studies in recent years.

Now comes the hard part: There are as many conflicting ideas on how to revamp the system as there are reports.

"We know what the goals are. But we still don't know how to achieve them," said James Rutherford, a leading science educator. "One reason we can't make any headway is we haven't had a clear national strategy on how to get from where we are to where we want to be."

As a result, there is disagreement on virtually every issue, such as whether to encourage or ban the use of calculators and computers, whether to concentrate on basic science literacy for all or for only the best and brightest, whether to delay math training until students master reading and writing and whether to focus resources on mentoring and other support systems.

Agreement on Need

The only consensus is on the critical need for more federal leadership and funding. But while the new Bush budget proposals represent a start in that direction, there is a long way to go, experts say.

Just last week the private Economic Policy Institute here, in an analysis of education spending, from kindergarten through grade 12, put the United States in 14th place among 16 industrialized nations in such spending as a percentage of national income, ahead of only Ireland and Australia.

The burgeoning crisis in science education is unprecedented since the Russians launched Sputnik in 1957 and triggered a new emphasis on science education.

The concern comes amid foreboding forecasts that the overwhelming majority of new workers entering the work force by the year 2000 will be female, black and Latino—groups that have fared the worst in science education.

Yet there is reason for hope, judging from the few nascent attempts to restructure science education around the country, including some in California.

In his speech, the President simply declared, without getting into specifics: "By the year 2000, U.S. students must be first in the world in math and science achievement."

Bush also mentioned several other "education goals" to be achieved by that year, including a high school graduation rate of "no less than 90%."

Despite the lack of details, educators were pleased by Bush's mention of education, in general, and the goal he set for science and math, in particular.

"That's a refreshing breeze," said Bill G. Aldridge, executive director of the National Science Teachers Assn. "We certainly don't need any more studies."

Here's what some of those studies show:

—29% of all high schools have no physics teacher, 17% no chemistry teacher and 8% no biology teacher.

—The typical high school biology textbook introduces more new words than the first two years of a foreign language class.

—Student disenchantment with science appears to take hold about the 8th grade. While 5th graders rank 8th among industrialized nations in science, by the time they reach 9th grade, they have dropped to 15th, according to National Science Foundation data.

—Of high school students who enter college intent on pursuing a science career, 40% drop out after the first course and 60% by graduation.

—College enrollment in science courses is at an all-time low and industry already is feeling the shortage.

The Aerospace Industries Assn. said that 67% of its members—including most of the top Pentagon and NASA contractors—are suffering from a shortage of scientists and engineers. And 55% report a shortage of skilled production workers.

In all, the NSF predicts a shortfall of 560,000 scientists and engineers by 2010.

To meet such a demand if the graduation rate for white males in those areas remained steady, U.S. colleges and universities would have to graduate twice as many women, five times as many blacks and seven times as many Latinos—beginning this year, says the congressionally chartered Task Force on Women, Minorities and the Handicapped in Science and Technology.

In the Administration's new budget, the NSF would get a 14% increase, to $2.38 billion, including $251 million for science education. Moreover, according to White House Science Adviser D. Allan Bromley, the Administration intends to double the foundation budget by 1993, from the base year of 1987.

In overall federal funding for science education, the President is proposing a 26% increase, from $841 million to $1.06 billion, spread among numerous agencies, such as the NSF, the Department of Education, the National Aeronautics and Space Administration, the Department of Energy and the National Institutes of Health.

Project 2061 Launched

Among the new attempts to reform science education is Project 2061, launched by the American Assn. for the Advancement of Science. It is named for the year that Halley's Comet will next pass Earth.

The project's current three-year phase enables teams of 25 teachers in six school districts, including the cities of San Diego and San Francisco, to work four days a month—and daily each summer—to design experimental K to 12 curricula, according to Rutherford, AAAS's chief education officer.

A shorter-term, federally funded project, launched by the National Science Teachers Assn., is designed to come up with new science core programs for 7th through 12th graders that abandon the century-old "layer cake" approach, which requires 10th graders to take biology, 11th graders chemistry and 12th graders physics, Aldridge said.

The goal, he said, is to expose more students—especially women and minorities—to a broad spectrum of science topics earlier but less intensely.

Where are the new scientists?

What if they gave a university and nobody came? Many predictions suggest that few young people will want to work as scientists in the 1990s

Jon Turney

IN THE 1980s, saving British science was a question of money. The main problem for universities and research councils was funding new projects. But in the 1990s all the signs point to a new problem dominating the science policy agenda—getting enough people into laboratories to spend even the money that is available.

A combination of factors, some common to other nations, some peculiar to Britain, suggests that this country may face a painful crisis in scientific recruitment in the near future. "The next five years will be critical", according to Sir David Phillips, chairman of the Advisory Board for the Research Councils.

The outlines of the potential crisis can be seen in demographic and employment trends. The first is the well-known dip in the number of 16- to 18-year-olds in our population, which began in 1984 and steepens after this year, and does not bottom out until 1996 (see Figure 1). The effect is that for every 10 students who left school in 1985, there will be only seven in 1995.

Some years after this, universities and colleges face a wave of academic retirements, as many of the present lecturers and professors reach the end of their careers toward the end of the 1990s. In addition, academic research laboratories face stronger competition for their share of the cream of new recruits from industrial sectors which need more and more technically qualified staff, and from the City. Keener competition makes the gap between the few thousand pounds a year a PhD student has to live on and the starting salary of, say, a newly qualified accountant on perhaps £12 000 wider than ever. In 1988, the proportion of new chemistry graduates choosing jobs in finance rose to 24·3 per cent, compared with 23·6 per cent in 1987, while the proportion of physics graduates going into finance rose from 15·5. to 17· ' per cent.

The demographic profile is similar in the US and France, and even worse in Italy, Germany and the Netherlands (see Figure 2). The academic retirement bulge is also a common problem, as most developed countries expanded their colleges rapidly in the 1960s. In the US alone, the National Science Foundation, predicts a shortfall of 675 000 scientists and engineers by 2006, so many more English-speaking researchers in other countries are likely to succumb to the lure of the dollar. Alternatively, they may decide to take advantage of the increased mobility the open European market will offer graduates after 1992 and depart for the continent.

So how many people are needed to sustain the British research effort? The best recent review of what Whitehall calls the "science base" is a study by Richard Pearson of the Institute of Manpower Studies, based at the University of Sussex, for the Advisory Board for the Research Councils. He found the statistics in a pretty poor state, but the main findings are clear. There were just under 50 000 researchers in research council laboratories, universities and polytechnics in the late 1980s. Around 28 000 were permanent teachers in higher education. Another 13 500 were working in universities or polytechnics on short-term contracts (of which more later). The rest, a little under 7500, were permanent or short-term employees of the five research councils, a total which has declined steeply in recent years because of cutbacks in the largely institute-based Agricultural and Food and Natural Environment Research Councils. These 50 000, not counting technicians and other support staff, are the science base's share of the million or so people in the British labour force with degree-level qualifications in science, technology, engineering or social science.

This means that the proportion of graduates needed to maintain the population of researchers in academic laboratories is pretty small. To this extent, the future supply problem is part of the more general problem of providing the skills a nation dependent on technology needs in the last

Association Affairs

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

RICHARD C. ATKINSON

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.

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.

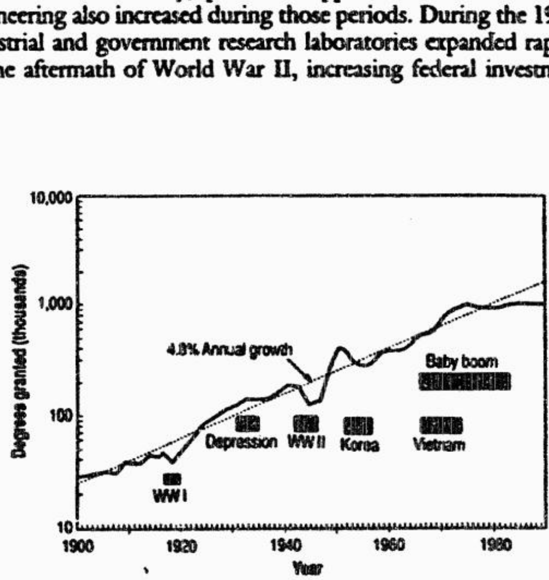

Fig. 1. Growth of U.S. baccalaureate and first professional degrees from 1900 to 1988. The dotted line shows a 4.8% annual growth rate. The baby boom bar identifies the group at 22 years of age. [Source: National Science Foundation]

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.

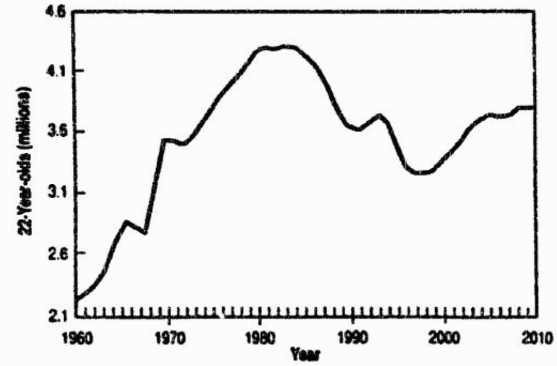

Fig. 2. Millions of 22-year-olds in the U.S. population. [Source: Bureau of Census, 1980 census]

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. [redacted] 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) stabilized 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 projected rate in 1990 will be 4.8%, 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-

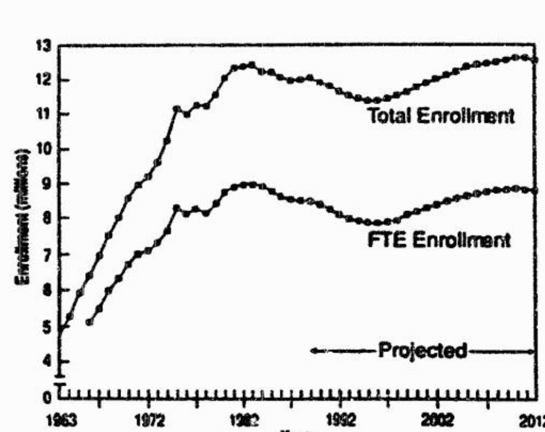

Fig. 3. College enrollment trends and projections from 1963 to 2012. Separate curves are presented for total enrollment (full-time plus part-time students) and full-time equivalent (FTE) enrollment. [Reprinted from (7) with permission, © 1989, Princeton University Press]

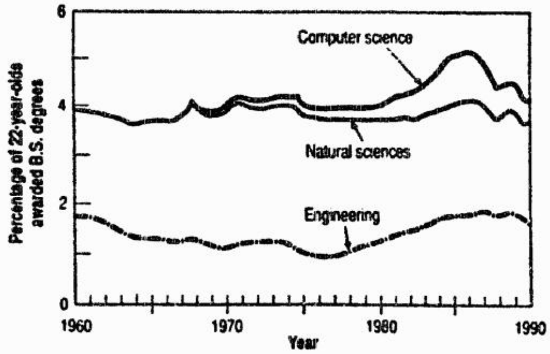

Fig. 4. Percentage of 22-year-olds awarded baccalaureate degrees in the natural sciences, computer science, and engineering. The three curves are cumulative; that is, each curve is the sum of all curves beneath it. [redacted]

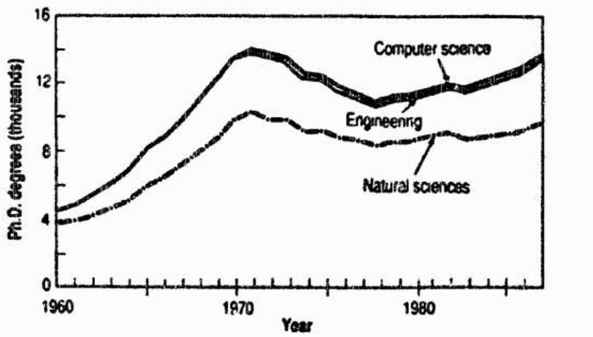

Fig. 5. Number of Ph.D. degrees in the natural sciences, computer science, and engineering from 1960 to 1987. The three curves are cumulative; that is, each is the sum of all curves beneath it. In 1987 production rates returned to the peak rate of 1971. [Source: National Science Foundation]

graphics changed, given that all other variables remain fixed at their values in a baseline year. [redacted]

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]