Chapter 1

Introduction

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Chapter 1

Introduction

Scientists and engineers, although comprising only 4 percent of American workers, have specialized skills vital to the national welfare. They widen human understanding by doing basic research and teaching, they develop and apply new technologies of every kind, and they keep the national manufacturing base running smoothly. Many people trained as scientists and engineers, but not actively employed in research or product development, also contribute to the well-being of the United States by bringing strong quantitative skills and an understanding of science to other occupations and fields. The Nation is well advised, therefore, to seek an adequate supply of people equipped and able to work in science and engineering.[1]

Recent trends have raised doubts in some minds about the adequacy of the future science and engineering work force.[2] Declining birth rates portend lower college and university enrollments, and thus fewer science and engineering majors. Each successive college-age cohort also contains a larger proportion of ethnic and racial minorities,[3] which historically have been poorly represented in science and engineering. Furthermore, the number of women planning science and engineering majors, after a decade of steady increases peaking in the late 1970s, has plateaued. Their gains in science and engineering baccalaureate degree-taking have not compensated for the more dramatic declines in participation by white males in the mid- 1970s. (Many white males, who in the past would have been likely to become scientists or engineers, in recent years have pursued majors in business instead; women are now following suit.) In general, interest in scientific and engineering careers, as indicated by annual surveys of incoming college freshmen, has been declining slightly for the last 3 to 5 years (although the annual output of baccalaureate science and engineering degrees is holding steady).[4]

These trends, combined with the past decade's sustained growth in science and engineering employment, have led some observers to forecast shortfalls in the science and engineering work force. The belief that the pattern of births determines the number of future scientists and engineers ("demographic determinism") is, however, open to question on a number of grounds:

- Women (and, to a lesser extent, Blacks and Hispanics) raised their rates of participation in science and engineering during the 1970s; while these gains seem to have leveled off in the 1980s, there is no reason to believe that participation cannot be further increased.
- Longitudinal surveys of students show that their choice of major and career plans change frequently, even up to the sophomore year of college, and their choices are influenced by market factors as well as by family and school.
- Elementary and secondary schools could do a better job of encouraging students in science and mathematics, thus expanding the talent pool.
- Ph.D. production has never tracked either the size of the birth cohort or the number of bac-

[1] "Equipped and able" implies high "quality." Because there is no agreement on definitions, it is difficult to measure the quality of students and of the education they are receiving. Quality is a pervasive factor in a scientist's or engineer's education and professional work; it is also an attribute embodied by a group, suggesting that trained personnel possess the knowledge and skills that make them versatile enough to satisfy a particular market demand when it arises. This assessment assumes that excellence is a paramount goal of public policy.

[2] Definitions of "scientist" and "engineer," and therefore estimates of the number of each, vary considerably by source. Throughout this assessment, the category "scientists and engineers" includes social scientists. Analyses that refer to "natural scientists and engineers" exclude social scientists. Classifying people by kind of science or engineering degree (baccalaureate, master's, or Ph.D.), rather than kind of work performed, is the more reliable basis for gauging future supply, including an important subset and focus of this assessment–the "research work force." For further discussion, see U.S. Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," staff paper, Jan. 21, 1987, pp. xv-xxii.

[3] Unless otherwise indicated, "minorities" refers to Blacks, Hispanics, and American Indians. Asian-Americans have the highest rates of participation in science and engineering of any group; thus, they are not considered with the other minorities. All of these analytical categories mask the heterogeneity within racial and ethnic groups, which is discussed below and in two forthcoming reports: U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering—A Technical Memorandum*, forthcoming, summer 1988; and U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering–A Technical Memorandum*, forthcoming, summer 1988.

[4] Alexander W. Astin et al., *The American Freshman: Twenty Year Trends* (Los Angeles, CA: Higher Education Research Institute, University of California at Los Angeles, 1987), pp. 14-19.

calaureate degrees granted. The number of natural science and engineering Ph.D.s awarded each year is small, between 12,000 and 14,000. Thus, programs that make the Ph.D. more attractive, or other factors leading to fluctuations in Ph.D. awards, can have sizable influence on the research work force.

OTA concludes that the changing demographics of the college-age population, including its racial and ethnic composition, are not necessarily predictive of either the size or quality of the future science and engineering talent pool. There are ways to increase participation of all kinds of students at each level of the American educational system. This system is more flexible and less predictable than the demographics suggest. Individual choices, affected by schools and the job market, can go far to meet society's future needs for scientists and engineers.

Should government intervention to increase the number of people equipped to do science or engineering be judged desirable, there is evidence to guide appropriate policy actions. This assessment summarizes the evidence and reviews policy options for creating an adequate future supply of scientists and engineers.

THE DEMOGRAPHIC OUTLOOK AND COMPOSITION OF THE TALENT POOL

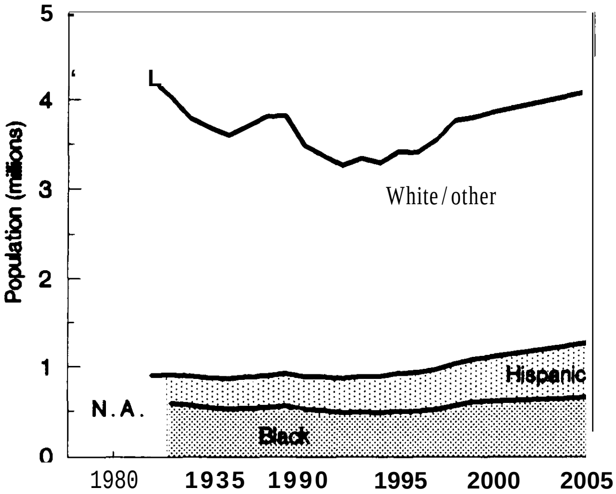
Like many other professions in U.S. society, science and engineering have historically drawn their members from the white male segment of the population. Today, the total college-age population is shrinking while its minority component—which has never been well-represented in science and engineering—is growing. The size of the college-age population at the turn of the century can be estimated reliably, since they have already been born. Census Bureau projections show that the number of U. S.-born 18-year-olds will fall until the mid-1990s before recovering substantially in the succeeding decade. As seen in figure 1-1, some describe this pattern as a "roller coaster." At the same time, the minority proportion of each cohort will rise slowly but steadily. (See figure 1-2.) In absolute terms, the number of Black 18-year-olds is also falling, although not as rapidly as whites. The number of Hispanic youth is rising. By the year 2000, over 25 percent of the college-age population will be Black or Hispanic.[5]

A simple estimate of future scientists and engineers is obtained by multiplying the population of college-age people in the birth cohort by the historical proportion of college students, by sex and minority composition, who major in science or engineering. Similar formulas are thought to govern each birth cohort's participation in graduate school and the eventual yield of Ph.D. scientists and engineers. This sort of simple extrapolation predicts declining output of scientists and engineers, which some take as a portent of inevitable personnel shortages in certain fields of science and engineering.[6]

[5] Harold L. Hodgkinson, *All One System: Demographics of Education, Kindergarten Through Graduate School* (Washington, DC: Institute for Educational Leadership, 1985). The increased number of non-Asian minorities will be concentrated in a few States such as California, Louisiana, Mississippi, New York, and Texas. There is also a public-private school difference: minority enrollment in public elementary and secondary schools nationwide is currently about 30 percent. The minority student population is much smaller in private schools.

[6] National Science Foundation, *The Science and Engineering Pipeline*, PRA Report 87-2 (Washington, DC: April 1987), pp. 1-2.

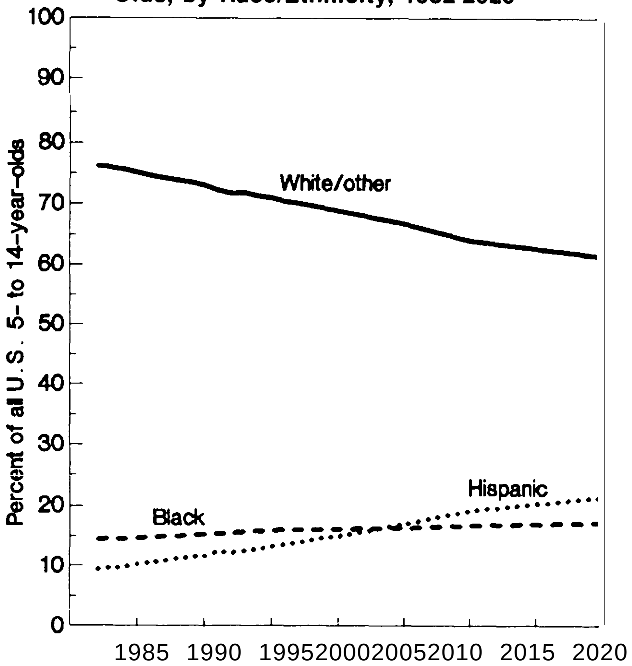
Figure 1-1.—Size of 18. Year-Old Population, by Race/Ethnicity, 1979.2005



NOTE: Series 17 projections—middle fertility, middle mortality, high net immigration.

SOURCE: U.S. Bureau of the Census, *Estimates of the Population of the United States by Age, Sex, and Race: 1980 to 1986*, Current Population Reports, Series P-25, No. 1000; *Projections of the Hispanic Population: 1983 to 2080*, Current Population Reports, Series P-25, No. 995; *Projections of the Population of the United States by Age, Sex, and Race: 1983 to 2080*, Current Population Reports, Series P-25, No. 952.

Figure 1"2.—PoDulation Projections of 5- to 14. Year-Olds, by Race/Ethnicity, 1982-2020



NOTE: Series 17 projections—middle fertility, middle mortality, high net immigration.

SOURCE: U.S Bureau of the Census, *Projections of the Population of the United States, by Age, Sex, and Race: 1983 to 2080, Current Population Reports, Series P-25, No. 952; Projections of the Hispanic Population, 1983 to 2080, Current Population Reports, Series P-25, No, 995.*

The number of minority high school graduates, particularly Black males, who apply for and enroll in college has been declining for the last 5 years. Large high school dropout rates persist among His-panics (only 60 to 70 percent of whom complete high school by age 24).[7] On the other hand, the Black and Hispanic communities are far from homogeneous. Life experiences of Blacks vary between the North and the South, and between rural and urban areas. The Black middle class is growing and, since educational success correlates more closely with social class than with race, Black participation rates may rise. The experiences of Hispanics vary considerably by their geographic origin: Mexican-American (Chicanos), Puerto Rican, and Cuban are the three origins on which data are sometimes reported.[8]

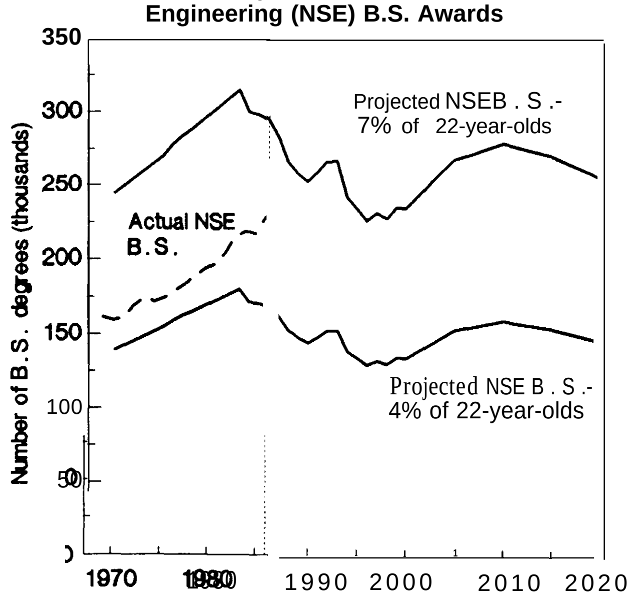
One cannot draw safe conclusions about future supplies of scientists and engineers on the basis of aggregate demographic trends alone (see figure 1-3). It is important to disaggregate and examine how students of different talents, sexes, race, and ethnicity flow through the education system to determine how the talent pool for scientific and engineering careers is formed and how degree aspirations are realized.

The future science and engineering work force begins with individual decisions to select and prepare for such a career. Among the factors that researchers cite as being important to this decision (summarized in table 1-1) are gender, race or ethnicity, parental occupations and other family influences, socioeconomic status, kind of school attended and courses taken, teaching practices employed, student's ability and talent, type of undergraduate college at-

[7] James R. Mingle, *Focus on Minorities: Trends in Higher Education Participation and Success (Denver, CO: Education Commission of the States and the State Higher Education Executive Officers, July 1987); U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, The Condition of Education: A Statistical Report, 1987 Edition (Washington, DC: 1987), pp. 26-28; U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, Digest of Education Statistics 1987 (Washington, DC: 1987), table 72.*

[8] *For most comparisons of student intentions, enrollments, and degree-taking, data are not available at this level of detail. Typically, the analytical categories of Black and Hispanic must suffice.*

Figure 1.3.- Projections of Natural Science/ Engineering (NSE) B.S. Awards



NOTE: OTA projections of natural science/engineering degrees assume a range of *4* to *7* percent of 22-year-olds obtain B.S. *degrees* in natural science/ engineering. The rate in 1986 was 5 percent (7,5 percent for all science/ engineering); the average rate from 1975-85 has declined from 8 to 7 percent for science/engineering, and has ranged from 4 to 5 percent for natural science/engineering (Center for Education Statistics degree data and U.S. Bureau of the Census population data). Natural science/engineering does not include the social sciences.

SOURCE: U.S. Department of Education, Center for Education Statistics.

Table 1-1 .—Factors Associated With Students' Majoring in Science and Engineering

The most important factors that contribute to students majoring in science and engineering	
Factor	Principal effect
Being in the academic track	Access to advanced courses and encouragement
Taking the most demanding science and mathematics courses	Preparation for college science or engineering major
Race and ethnicity—being white or Asian rather than Black or Hispanic	Cultural acceptance of science or engineering **as a** career
Sex—male rather than female	Cultural acceptance of science or engineering as a career; no childbearing/family conflicts with career
Family socioeconomic status—being able to afford college	Well-educated, school-oriented parents; access to good schools; information on negotiating the system
Parents—having **a** parent who is a scientist or engineer	Role model, early and substantial exposure to science as process
Early research participation	Early exposure to how science really works
Intrinsic interest—finding science enjoyable	Curiosity about mathematics and science courses
Having a good, enthusiastic science teacher and/or guidance counselor	Heightened student interest and achievement; positive attitudes toward science; college attendance
Participation in an intervention program	Development of interest, enthusiasm, self-esteem
Being in a science-intensive school	Access to courses, labs, peers, and teachers—a science environment
Factors that may contribute to students majoring in science and engineering	
Factor	Likely principal effect
Having a well-qualified science teacher	More likely to be knowledgeable about science and communicate positive attitude
Meeting or observing a scientist or engineer, having a role model	Self-identification with science
Being taught using many science experiments ("hands-on" experience)	Heightened interest and knowledge of reality of science
Being in a school district with a science coordinator	School is likely to have better curricula and facilities
Factors about which there is little evidence of contribution	
Factor	Effect if any
Being in summer science camp	Self-confidence and enthusiasm developed from science being a voluntary activity
Television (e.g., "3-2-1 Contact")	Heightened enthusiasm, self-concept, and knowledge about science
Science centers and museums	Alternative to classroom; "Explainer" experience builds academic self-esteem
National Science Foundation mathematics and science curricula	More experimental work, more relevant content
Having a teacher that has been through a National Science Foundation teacher institute	Teacher more interested in and knowledgeable about science
Having a good textbook	More likely to maintain interest in science classes
State and local graduation requirements	More likely to take more and higher level mathematics and science classes
Being in a school or district that benefits from Department of Education Title II funding	Better trained teachers, more equipment
Career seminars and brochures	Better knowledge of what science and engineering careers are about
Teacher salaries and school funding	Richer schools can afford to do more in science, get better teachers, and retain them

SOURCE: Office of Technology Assessment, 19S8, tended, early participation in scientific research, and availability of graduate funding. While the probability that a woman, Black, or Hispanic will major in science or engineering is many times lower than that of a white male, it is not easy to express and measure exactly *what* it is about being female, a member of an ethnic minority, or a white male that leads to these behaviors."

The complexity of such questions of cause and effect is well described by a study of the causes of the national decline in achievement test scores, recently published by the Congressional Budget Office. U.S. Congress, Congressional Budget Office, *Educational Achievement: Explanations and Implications of Recent Trends* (Washington, DC: August 1987).

It is not necessary to understand all the causes of cultural, racial, ethnic, and sex differences that underlie the propensity to major in science and engineering before seeking to make changes to the system. It is helpful, however, to understand how coming demographic changes will translate into the passage of talent through the education system. Although the talent pool forms as early as junior high school, its composition evolves from students who are interested in science and mathematics in the early grades and attend college, to those who major in science or engineering and actually earn degrees in these fields.

THE SCIENCE AND ENGINEERING "PIPELINE"

The formal education system is seen by many as a kind of "pipeline" through which students pass on their way to science and engineering careers. The pipeline is a model of the process that refines abundant "crude" talent into select "finished" products as signified by award of baccalaureate, master's, and doctorate degrees (for an example, see figure 1-4). According to this model:

- "Although the talent pool seems to reach its maximum size before high school, migration into the pool continues to occur during grades 9 through 12. However, after high school, migration is almost entirely out of, not into, the pool."[10]
- "The early years (prior to 9th grade) are critical in recruiting students to the sciences. Socioeconomic status (parental educational attainment, occupation, and income) is a strong influence at this stage, affecting values and formal and informal educational activities that have a major impact on the development of children's interests and abilities."[11]
- "[In high school] the influence of aptitude and sense of competence are critical . . . . Particularly crucial are the decisions students make regarding enrollment in advanced mathematics courses. "
- "Major losses to the science and engineering talent pool occur during the college years. This signals the need to pay more attention to the quality of undergraduate programs—the extent of interaction between students and senior faculty, the balance between curricula designed to weed students out and curricula designed to nurture students along, and the availability of undergraduate research experiences. "
- "The transition from undergraduate to graduate school is another big loss point . . . . Students' perceptions of opportunity are key here. The availability of jobs, income potential, job security, and occupational status all come into play."

The pipeline model emphasizes the links between all stages of formal education, from kindergarten through graduate school. It suggests that an early display and recognition of talent is essential. Without the traditional preparatory mathematics and science courses, students are left behind, unable to catch up if they aspire to a scientific or engineering career. Yet losses of aspiring science and engineering students occur at each juncture in the pipeline. While an attitude of exclusivity has typified the cultivation of science and engineering talent, a broader base of learners has always been possible. The National Academy of Sciences concludes:

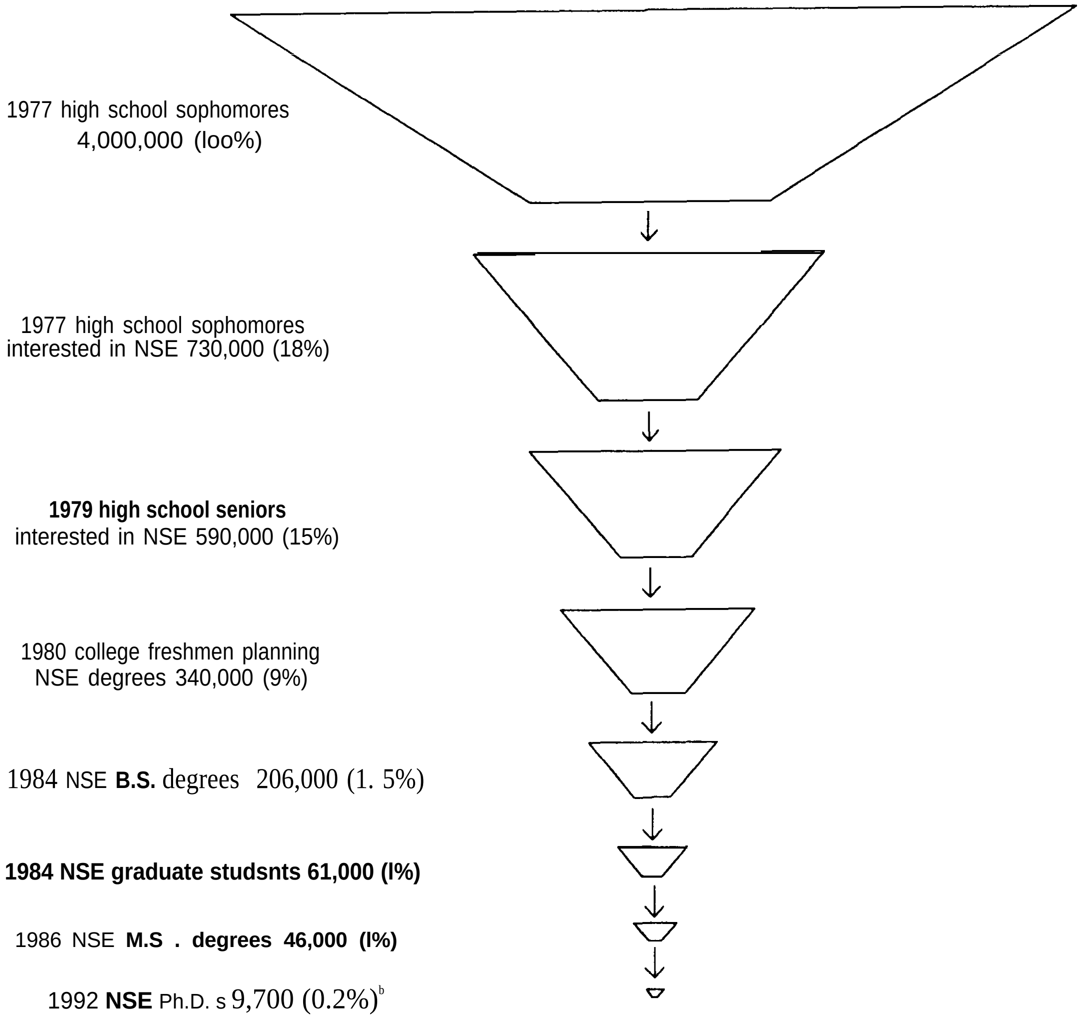
> Every educational and developmental stage is a potential point of intervention, and a comprehensive approach to nurturing science and engineering talent must address the whole pipeline.[12]

[10] Sue E. Berryman, *Who Will Do Science? A Special Report* (New York, NY: The Rockefeller Foundation, 1983), p. 7.

[11] Government-University-Industry Roundtable, *Nurturing Science and Engineering Talent* (Washington, DC: National Academy Press, 1987), p. v. Quotations below are from this source unless otherwise noted.

[12] Ibid.

Figure 1.4.—Natural Science/Engineering[a] Pipeline: Following a Class From High School Through Graduate School



[a]Natural science/engineering (NSE) includes physical, mathematical, and life sciences, and engineering, but not the social sciences.
[b]National Science Foundation estimate, based on the historical rate in NSE of 5 percent of B.S. graduates going on for Ph.D.s (using an 8-year average lag time from B.S. to Ph.D.). If market conditions increase demand for Ph.D.s, then this estimate may understate future production of NSE Ph. D.s. The number of NSE Ph. D.s in 1988 was about 12,000, or over 7 percent of NSE B.S. graduates in 1978 (Center for Education Statistics degree data). Assuming 7 percent of 1988 B.S. graduates rather than 5 percent go on for Ph. D.s would project 14,400 NSE Ph. D.s in 1992 rather than 9,700. Other methods of prediction (for instance, estimating Ph. D.s as a percent of the 30-year-old age cohort) show similar responsiveness to changing participation rates and assumptions. The Ph.D. population is very small and responds to changing conditions in academia and the job market, so that population-based estimates should be taken as rough indicators or warning signals rather than as solid predictions.

NOTE: These National Science Foundation estimates indicate the general pattern of the NSE pipeline, but are not actual numbers of students in the pipeline. (For instance, actual natural science/engineering B.S. production was 209,000 in 1988, Center for Education Statistics data.) The estimates are based on data from the U.S. Department of Education-sponsored National Longitudinal Study of 1972 Seniors (for the high school senior through graduate school transitions) and High School and Beyond Study of 1980 Seniors (for the high school sophomore to high school senior transition). Since the National Longitudinal Study was conducted, student interest in NSE majors has risen, but it is not yet clear whether trends in student interest with time will follow the pattern of 1972 high school seniors revealed by the National Longitudinal Study.

SOURCE: National Science Foundation, *The Science and Engineering Pipeline,* PRA Report 87-2, April 1987, p. 3; and personal communication with National Science Foundation staff.

Clarifying the Portrayal of Supply

In reality, each tier of education has to work with the students with which it is fed. In recent years, each tier has voiced serious complaints about the quality of students emerging from the preceding tier. Nevertheless, the task is to do the best with the available students rather than bemoaning the situation and laying blame.[13] OTA finds that the pipeline is not filled solely by the determined core of committed students who display early promise, high achievement, and drive. Estimates suggest that one-quarter of those who eventually go on to major in science and engineering come from outside the academic (college-preparatory) curriculum track.[14]

In the long run, the greatest influence on the size and quality of the science and engineering work force is elementary and secondary education, for it is the schools that interest and prepare, or fail to prepare, students with the necessary background in science and mathematics. Schools are asked to do many things for students, including inspiring an appreciation for knowledge and instilling good study habits for its pursuit. One of their tasks is identifying and sorting talent (the "college-bound") for college study, which targets students for certain careers. Schools, in effect, are purveyors and engineers of culture, as well as being gatekeepers to the professions. This duality is expressed in competing desires for both mass *and* elite education: schools are expected to arrange programs for the "gifted and talented" and programs to bootstrap the disadvantaged and learning disabled. Against these objectives, the challenge is to prevent mathematics and science education from being shortchanged.

Schools, therefore, can do a lot to prepare or inhibit students in science and engineering, through actions such as course offerings, curricula, testing, and tracking. Calls today for "technological literacy" echo the post-Sputnik battle cry that raised the level of mathematics and science consciousness—and content—in the schools. But the teaching of mathematics and science leaves much to be desired —content at the elementary level, pedagogical techniques in high school, The training of science teachers, with its emphasis on teaching methods, often fails to inculcate in future science teachers an understanding of and enthusiasm for science as a process of inquiry, and not just a bundle of facts.[15]

The pipeline model is still a black box of the educational process that acts upon students. It portrays the net effects of this process as a dwindling supply of talent, with its composition in flux, that has been sorted and guided toward future careers that require additional education. As an analytical tool, the pipeline illuminates choices and motivations both within students and schools. Each is future-oriented, anticipating a market that will match skills and interests to expected employment needs. Although the match is imperfect, the funding of these needs creates "demand."

Anticipating Future Demand for Scientists and Engineers

The health of the economy, technological changes, and shifting government priorities, which cannot be projected with any useful degree of accuracy, all affect future demand for scientists and engineers (see table I-2). Historically, this demand has been rising, and many analysts expect that growth to continue; but growth will vary significantly from field to field. The complexity of analyzing changes in demand for the relatively small science and engineering work force confounds forecasts and increases

[13] There is widespread disenchantment with the overall quality of elementary, secondary, and even higher education, which is perceived to be declining, while its cost is rising in real terms. See, for example, National Commission on Excellence in Education, *A Nation at Risk* (Washington, DC: April 1983); Carnegie Forum on Education and the Economy, *A Nation Prepared: Teachers for the 21st Century, The Report of the Task Force on Teaching as a Profession* (New York, NY: Carnegie Forum, May 1986); *The Chronicle of Higher Education*, "Text of Presidents' Open Letter Urging Colleges To Be Active in School Reform," vol. 34, No. 4, Sept. 23, 1987, p. A23.

[14] This estimate is based on an analysis of the High School and Beyond survey, class of 1982. Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, September 1987. Though variations in the preparation and paths to a career in science or engineering are not well-understood, a detailed analysis of the relations ip between course-taking and intended college major is contained in Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, op. cit., footnote 3.

[15] Edward B. Harvey and Lorna R. Marsden, "Excellence and Equality: The Contradiction in Science Teaching in America," *Science Teaching: The Year in School Science 1985*, Audrey B. Champagne and Leslie E. Hornig (eds.) (Washington, DC: American Association for the Advancement of Science, 1986), pp. 126-1 W; Iris R. Weiss, "Pre- and In-Service Training, Roles of Various Actors, and Incentives to Quality Science Teaching," OTA workshop summary, September 1987.

Photo credits: John Jernegan, MESA Program (inset); The Science Museum of Virginia and Association of Science and Technology Centers

The future supply of scientists and engineers could be improved by many actions. In the long term, the number of minorities that enter these fields can only be increased if more attention is paid to elementary and secondary education, where the minority talent pool is unduly curtailed. Here, minority students participate in an intervention program at the Lawrence Hall of Science, California, which offers special courses designed to interest students in science. Highly able white students could also be encouraged toward science and engineering; many now opt for other careers, such as business, instead. In either case, the same techniques, such as hands-on experiments in science, help stimulate students' interest in, and understanding of, science.

uncertainty, especially at the level of individual fields. "

Federal actions, because of their pervasive effects on the economy and on the size and location of research and development (R&D) activities, have strong effects, both direct and indirect, on the demand. Spot shortages and surpluses in some disciplines seem unavoidable as long as we maintain a dynamic economy. Recent examples include certain computer-related engineering and science subfields, and resource geology before that. Market forces tend to correct such shortages before policy measures

[16]Concern *for and methods of projecting employment demand for scientists and engineers were reviewed in U.S. Congress, Office of Technology Assessment,* Demographic Trends and the Scientific and Engineering Work Force—A Technical Memorandum, OTA-TM-SET-35 *(Washington, DC: U.S. Government Printing Office, December 1985), esp. ch. 3. OTA concluded first, that labor markets for scientists and engineers display considerable flexibility. These markets send signals to potential new entrants and to existing participants causing them to realign their education and training according to market needs. Second, trends toward increasing participation by women, older students, and minorities will* push *overall participation rates up, even as birth cohorts shrink.*

Table 1-2.—Factors Influencing Demand for and Supply of Scientists and Engineers

Factors that increase demand
- Increase in basic research
- Increase in mission research
- Economic growth
- Increasing technological sophistication of U.S. manufacturing and services due to scientific progress, international competition, and demand for a higher standard of living
- Increase in science and engineering higher education enrollments (causing an increased demand for faculty)

Factors that decrease demand
- Sending R&D and engineering offshore
- Decrease in basic or mission research
- Economic recession

Factors that shift demand between disciplines
- Technological change and scientific advance of all kinds, which render some disciplines obsolete while creating new ones
- Automation of engineering functions by means of computer-aided design and manufacturing and other communication and information technologies
- Using technicians for some tasks now undertaken by scientists and engineers

Factors influencing supply
- The size and rate of increase or decrease of demand for scientists and engineers modulated by the salary advantage for scientists and engineers and the national level of R&D expenditure
- The number of births and their racial and ethnic composition
- Education at elementary, secondary, and higher levels
- Permanent and temporary immigration of foreign scientists and engineers
- Federal and State initiatives to encourage different types of institutions to award more science and engineering degrees or award degrees at a higher level
- Legislation and other actions that affect the opportunity to attend and afford college or graduate education

SOURCE: Office of Technology Assessment, 1988.

would.[17] Nevertheless, policy is needed to ensure a baseline capacity to adjust to market changes.

Historically, scientists and engineers have experienced lower unemployment than other professionals. Based on employer reports and salary offers to new graduates, at present, no long-term shortages are apparent. *s Salaries are an indicator of demand; salary increases in a field or industry signal a need to attract more trained personnel, both new graduates and those elsewhere in the work force. For example, spot shortages in certain engineering specialties (such as those supporting the energy boom of the 1970s and the electronics boom of the early 1980s) occasionally drive salaries up rapidly before subsiding.[19]

When the number of students in the educational system (usually at the undergraduate level where enrollments indicate the likely future distribution of degrees):

> . . . is deemed too low in a given field, as compared with an anticipated need for their services, policymakers can deploy strategies designed to increase this number. Broadly speaking, these strategies seek to increase the percentage of students at that stage majoring in the shortage field or to reduce student attrition up to that stage. . . . It appears that strategies designed to reduce the attrition from natural sciences and engineering coursework are more realistically based than field-specific strategies.[20]

[17]More pronounced shortages are created by Federal research missions, such as the Apollo program in the 1960s. See Arnold S. Levine, "The Apollo Program: Science and Engineering Personnel Demand Created by a Federal Research Mission," OTA contractor report, October 1986.

[18]National Science Foundation, *National Patterns of Science and Technology Resources*, NSF 86-309 (Washington, DC: 1986).

[19]Engineering salaries over the past 30 years have been flat, in real dollars. The most recent information on job offers to science and engineering graduates indicates that although salaries are not increasing—a sign of a steady supply—at all degree levels scientists and engineers enjoy the highest average starting salaries relative to other fields. Commission on Professionals in Science and Technology', *Salaries of Scientists, Engineers, and Technicians* (Washington, DC: October 1987). A primary source of salary data is the annual College Placement Council survey, which notes that average salary offers to women in 1987 were lower than to men in all fields except engineering (see *Manpower Comments*, September 1987, pp. 12-1 3).

"'National Science Foundation, op. cit., footnote 6, p. 2.

STRATEGIES TO MEET FUTURE NEEDS: FEDERAL AND STATE ROLES

In articulating concern about future numbers of scientists and engineers, politicians and industry leaders have linked educational needs to improving the Nation's industrial competitiveness in a global economy. Several strategies exist to hedge against shifting national needs and any enduring mismatches between increasing future demand for scientists and engineers and the supply that would result from unperturbed historical trends. Strategies that emphasize the supply of talent must focus on education and the schools; therefore, the principal policy actors are Federal and State Governments. Various other institutions, however, have roles to play.

Strategies are of two general types: retaining students interested in a science or engineering career by reducing their attrition from the talent pool, and recruiting new students to enlarge the pool. One specific strategy is to encourage more students of the kind that have traditionally entered these careers, predominantly highly able white males, to shift from their current careers of choice (such as business) back to science and engineering fields. Another is to enthuse the vast majority of students who are now disaffected from science in elementary and secondary education for whatever reason—poor teaching, undemanding curricula, or belief that science and engineering are too difficult. Still another strategy is to provide more support to women and minorities to enter careers in science and engineering. There is now emerging, in particular, a considerable body of empirical knowledge on the things that can be done to encourage women and minorities to study science and engineering. Such actions include the introduction of role models, the use of intervention programs, familiarizing teachers with the subtle ways by which they discriminate by race and by gender, and creating a classroom climate of high expectations and self-esteem among students.[21]

The surest strategy of all, and one that the United States has employed since these lands were first colonized, is to welcome immigration of scientists and engineers. American science and engineering has reaped longstanding benefits from this ready resource. At the graduate level, this policy is being applied in the face of declines in the numbers of U.S. citizens entering graduate school. The chief U.S. worry is an over-reliance on foreign talent, though it is unclear how much is "too much."[22] There are also ways of reducing the demand for U.S. scientists and engineers, including reducing spending on basic and applied research, making more intensive use of technicians, or taking R&D overseas and thus using foreign scientists and engineers.

Federal Influence on the Production of Scientists and Engineers

Federal R&D initiatives–although not intended primarily as personnel development programs—shape the research job market, the availability of academic research funds (including research assistantships), and consequently, the demand for Ph.D.s. These effects are amplified by the private sector's job markets, too, when—as is often the case—Federal programs influence industry R&D decisions. Undergraduate enrollments also respond to other Federal initiatives: the GI bill led to increases (especially of male veterans returning home after World War II),[23] Title VI of the Civil Rights Act of 1964

[21] Shirley M. Malcom, *Equity and Excellence: Compatible Goals, An Assessment of Programs That Facilitate Increased Access and Achievement of Females and Minorities in K-12 Mathematics and Science Education* (Washington, DC: Office of Opportunities in Science, American Association for the Advancement of Science, December 1984), esp. pp. 14-20.

[22] Importing talent is controversial and risky, since imports may disturb domestic labor markets and since concerns about "brain drains" to the United States are already causing some foreign governments to consider ways to stem the losses from their own talent pools and to repatriate their citizens. Some also cite the oral communication skills of foreign-born faculty and teaching assistants as a problem in undergraduate science and engineering education. See Elinor G. Barber and Robert P. Morgan, *The Impact of Foreign Graduate Students on U.S. Engineering Education* (New York, NY and St. Louis, MO: Institute of International Education and Center for Development Technology, Washington University, June 1987), pp. 69-79.

[23] The Korean and Vietnam wars did not; enrollment increases—which occurred more in 2- than 4-year institutions after Vietnam—were proportional to population growth. U.S. Department of Commerce, Bureau of the Census, *School Enrollment—Social and Economic Characteristics of Students: October 2976* (Washington, DC: February 1978), pp. 1-4.

boosted college attendance by minority students,[24] and Title IX of the 1972 Education Amendments increased the participation of women in higher education.[25]

The most demonstrably effective direct Federal investment in science and engineering education of Ph.D.s is the funding of graduate fellowships in specific fields of study. Though few in number, fellowships and traineeships help produce Ph.D.s and encourage students to shift their postdoctoral plans.[26] There are few timely solutions to shortages of specialized skills other than the versatility of those already in the work force. Fine-tuning the educational system to affect the future production of scientists and engineers to meet anticipated transient conditions of changing job markets is difficult. The lag times in the education system, especially for Ph.D. scientists, are long compared to the usual duration of shortages in particular employment markets.

A long-term program to increase the pool of potential scientific and engineering talent and the quality of those who eventually become scientists and engineers will have to tackle the schools as the principal institutions that motivate, attract, and deter students from various careers.[27] Other long-term measures might include:

- Federal support of special intervention programs to recruit and retain women and minorities in science and engineering (and eventually to institutionalize in the schools and colleges the interventions that work).
- Federal support for the propagation of higher education environments that are unusually productive of baccalaureates who eventually gain Ph.D.s in science and engineering. (These environments include not only research universities, but also others that excel at integrating teaching and research for particular populations: private liberal arts colleges, including a subset of predominantly women's colleges and traditionally Black institutions.[28])
- Focusing the responsibility for precollege mathematics and science (addressed to teachers and students alike), as well as undergraduate science and engineering programs, experiments, and evaluations, on the National Science Founda-

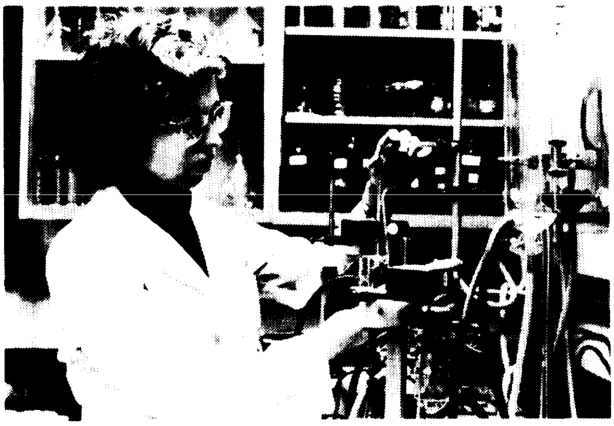


Photo credit: Carl Zitzmann, George Mason University

The Federal Government has a vital role in supporting the infrastructure of graduate science and engineering education in order to ensure an adequate supply of researchers. Federal support comes in several forms, recognizing the fundamental links, as well as the differences, between education and research at the graduate level. The principal forms are institutional support, research contracts, and fellowships and traineeships awarded to students. In seeking to maintain the educational infrastructure for science and engineering, Federal policy needs to address each of these forms.

[24] Meyer Weinberg, *The Search for Quality Integrated Education: Policy and Research on Minority Students in School and College* (Westport, CT: Greenwood Press, 1983), pp. 306-319.

[25] Phyllis Wei-Erh Cheng, University of Southern California, "The New Federalism and Women's Educational Equity," unpublished manuscript, December 1987.

[26] The postdoctoral fellowship is a multipurpose measure. For the recipient, it can be an award of distinction, a period for augmenting one's technical skills, and/or a way of postponing entry to a fallow market of, say, limited academic opportunity. Interpretations of postdoctorates as a post-Ph. D. status and activity must take into account both impacts on the work force and the individual career. See National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy press, 1981); William Zumeta, "Anatomy of the Boom in Postdoctoral Appointments During the 1970s: Troubling Implications for Quality Science?" *Science, Technology, & Human Values*, vol. 9, No. 2, spring 1984, pp. 23-27.

[27] Families, peers, and out-of-school influences (e.g., churches and community organizations) interact with schools, teachers, and counselors to underscore (or undermine) the image of science and engineering in American culture. See Robert E. Fullilove, "Images of Science: Factors Affecting the Choice of Science as a Career," OTA contractor report, 1987. The contrast of these interactions in Japanese culture is explored in William K. Cummings, "International Comparison of Science and Engineering Work Force Policies: Japan," OTA contractor report, 1987.

[28] See, for example, M. Elizabeth Tidball, "Baccalaureate Origins of Recent Natural Science Doctorates," *Journal of Higher Education*, vol. 57, No. 6, November-December 1986, pp. 606-620; Gail E. Thomas, "Black Students in U.S. Graduate and Professional Schools in the 1980s: A National and Institutional Assessment," *Harvard Educational Review*, vol. 57, No. 3, August 1987, pp. 261-282.

tion's (NSF) Science and Engineering Education (SEE) Directorate.

Interaction of the States and the Federal Government

Although the Federal role in the national education system is old (through the Northwest Ordinance, it predates the U.S. Constitution), it is limited. Under the 10th Amendment to the U.S. Constitution, education is a power reserved to the States and the people and, as such, is taken very seriously by State legislatures and governments; it is the largest single item of State spending.[29] States, in turn, delegate their responsibilities for education to other bodies. In the case of elementary and secondary education, the provision and some of the funding of education are the charges of locally elected school districts, which hire their own teachers and staff and make many curricular decisions. Public university and college systems have extensive autonomy over higher education, but rely on States for funding.

Two Federal agencies, NSF and the Department of Education, specifically address science and engineering education. The mission agencies,[30] through R&D and a potpourri of programs, also contribute mightily. Under its enabling legislation, NSF is specifically charged with monitoring and maintaining the quality of the science and engineering work force. It is authorized and directed:

> . . . to initiate and support basic scientific research and programs to strengthen scientific research potential and science education programs at all levels in the mathematical, physical, medical, biological, engineering, social, and other sciences. . . .[31]

Even with the transfer of some functions to the Department of Education through later amendments and reauthorizations, the promotion of basic research and of education in science remains equal within the NSF mandate.[32] Until very recently, this mandate has been narrowly interpreted by the research community and the NSF leadership as mainly the provision of Federal basic research funds to the Nation's colleges and universities.[33]

The Department of Education is responsible for overseeing the general health of the entire national education system. It operates many major programs that, in fiscal year 1988, will provide $20 billion to States, school districts, colleges, and universities—approximately 6 to 7 percent of the national total spent on education.[34] Its charter calls for the collection of a huge variety of data, statistics, and research on education, and categorical support for students. The division of functions between NSF and the Department of Education is mirrored in Congress, where different committees have oversight and appropriations authority over research and education.

The overall Federal role in science and engineering education, exercised through NSF, the Department of Education, and the mission agencies, is most prominent at the undergraduate and graduate levels (see table 1-3). Graduate education relies heavily on Federal student, institutional, and research support. Financial aid programs, Federal research support, and the successive mounting and abandonment of research-intensive domestic and military programs influence the supply of and the demand for scientists and engineers. In particular, there is ample evidence that Ph,D.s, overall and in a given field, can be "bought" by offering fellowships, traineeships,

[29] U.S. Department of Commerce, Bureau *of the Census, State Government Finances in 1985,* GF85-No.3 *(Washington, DC: December 1986).*

[30] *Mission agencies carry out the Federal responsibility in such areas as health, defense, space, energy, and agriculture. This division of labor corresponds to the Office of Management and Budget's categories in the Federal budget. The main research and development agencies are the National Institutes of Health, the Department of Defense, the National Aeronautics and Space Administration, the Department of Energy, and the U.S. Department of Agriculture.*

[31] 180 *U.* S.C.A.(Ch. *16, National Science Foundation, Sec. 1862. Functions), 1987, p.* **187.**

[32] It *is debatable whether an equal emphasis on research and education should translate into relatively equal dollars. Clearly, this has not been the case, In terms of outcomes, it is comparable to weighing the returns from investing a research fellowship in one Ph.D. candidate versus supporting a summer institute experience for three or four high school science teachers. The dollar equivalency will yield a measurable near-term effect on one student and his or her career, but an indirect, longer-term effect on perhaps untold numbers of students. Which is the better, or more effective, Federal investment?*

[33] The *emphasis of the current National Science Foundation leadership on centers and corporate participation in applications-oriented university-based research, in addition to individual investigator projects, is a clear break from the* post-Vannevar *Bush tradition. See Deborah* Shapley *and* Rustum *Roy, Lost at the Frontier: U.S. Science and Technology* Policy *Adrift (Philadelphia, PA: 1S1 Press, 1985), esp. chs. 1-3.*

[34] U.S. *Department of Education,* *Digest of Education Statistics 1987,* op. cit., footnote *7,* pp. *25, 263-267. (The percentage is based on data for fiscal year 1985.)*

Table 1-3.--Major Federal Programs Affecting the Education of Future Scientists and Engineers

National Science Foundation ($100.$300 million)[a]
- K-12: teacher training, curriculum and materials development, informal education, research, recognition program for exemplary teachers, research participation for high school students
- Undergraduate: research participation, instrumentation, undergraduate creativity awards
- Graduate: graduate fellowships, graduate fellowships for minorities, research assistantships via research contracts, engineering fellowships

US. Department of Education ($200-$500 million)
- K-12: Title 11, Education for Economic Security Act, used primarily for science and mathematics teacher training; magnet school grants (not specifically targeted to science and engineering); discretionary programs
- Undergraduate: Pen Grants (not specifically targeted to science and engineering), Minority Science Improvement Program, cooperative education (about 15-30 percent of cooperative students are in science and engineering)
- Graduate: Minority Institutions Science Improvement Program; Graduate and Professional Opportunities Program; Javits Predoctoral Fellowships

National Institutes of Health ($400.$500 million)
- K-12: research apprenticeships for minorities
- Undergraduate: Minority Access to Research Careers Program, Minority Biomedical Research Support
- Graduate: National Research Service Awards Predoctoral Training Grants, research assistantships funded via research contracts, National Institutes of Mental Health Minority Fellowships

Other agencies with substantial science education efforts
K-12
- U.S. Department of Agriculture: 4H, research apprenticeships
- U.S. Department of Defense: research apprenticeships at laboratories
- U.S. Department of Energy: Prefreshman Engineering Program, for women and minorities; student research apprenticeships and teacher training institutes at national laboratories
- National Aeronautics and Space Administration: research apprenticeships, teacher workshops, and resource centers

Undergraduate
- U.S. Department of Agriculture: Land Grant allocations (not specifically targeted to science and engineering)
- U.S. Department of Commerce: National Oceanic and Atmospheric Administration Sea Grant Program
- U.S. Department of Defense: Reserve Officer Training Corps (ROTC) (about 75 percent of funds are spent on science and engineering majors)
- U.S. Department of Energy: University-Laboratory Cooperative Program for summer research
- Department of Health and Human Services: Health Careers Opportunities Program

Graduate
- U.S. Department of Agriculture: Land Grant allocations (not specifically targeted to science and engineering)
- U.S. Department of Defense: research assistantships via research contracts, graduate fellowships
- U.S. Department of Energy: fellowships in particular research fields, summer research participation grants, research assistantships funded via research contracts
- U.S. Environmental Protection Agency: research assistantships via research contracts
- National Aeronautics and Space Administration: graduate fellowships, minorify graduate fellowships, research assistantships via research contracts

[a]NOTE: Estimates of annual spending are from 1988. With the exception of those in the National Science Foundation, each Of the programs listed here is funded at the level of at least $1 million per year. Institutional development programs are omitted.

SOURCE" Office of Technology Assessment, 1988.

and research assistantships, which lessen the burden of cost to students while offering them valuable apprenticeships as they progress toward the degree.[35] In the near term, this step is probably the most effective way to increase the-output of Ph.D.s, who form the core of our research scientists and engineers. In the longer term, research support and a robust university infrastructure sustain the Nation's capacity to replenish the supply of scientists and engineers, so long as those entering college are both interested and prepared for these careers.

From the perspective of Congress, however, elementary and secondary education is at the same time the part of the system in greatest need of improvement and also the most removed from direct Federal influence. National Science Foundation funding for elementary and secondary mathematics and science education peaked in fiscal year 1964, but even then represented less than one-half of 1 per-

"Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need To Know* (Washington, DC: Association of American Universities, 1986); Michael T. Nettles, *Financial Aid and Minority Participation in Graduate Education, A Research Report of the Minority Graduate Education Project* (Princeton, NJ: Educational Testing Service, 1987).

cent of all spending on elementary and secondary education.[36] NSF programs have focused principally on curriculum development and teacher training. Since fiscal year 1984, budget support for mathematics and science education has grown conspicuously in response to congressional initiatives.[37]

[36]Michael S. Knapp et al., "Part Three: NSF's Investment History in K-12 Science Education," *Opportunities for Strategic Investment in K-12 Science Education: Options for the National Science Foundation, Volume 2* (Menlo Park, CA: SRI International, June 1987); U.S. Department of Education, *Digest of Education Statistics 1987,* op. cit., footnote 7, p. 25.

[37]In a National Science Foundation budget totaling $1.7 billion in fiscal year 1988, the Science and Engineering Education Directorate increased by 40 percent to $139 million. Following the reinstatement of the Science and Engineering Education Directorate in 1982, funding for elementary and secondary programs has increased steadily from $3.8 million in fiscal year 1983 to an estimated $80 million to $85 million in fiscal year 1988.

NATIONAL NEEDS AND THE GOALS OF SCIENCE AND ENGINEERING EDUCATION

The national goal of maintaining and invigorating a science and engineering work force demands policy efforts on three fronts to create adequate numbers of well-prepared students available to serve as scientists and engineers. First, capable young people must be welcomed throughout the educational process. Second, their talents must be nurtured by elementary and secondary schools and institutions of higher education. Third, they must perceive employment opportunities that utilize their talents by providing fulfilling work.

The pool of potential talent needs to be large and versatile, whether or not there is reason to fear a future shortage of scientists and engineers. To the extent that the education system unduly limits the talent pool by prematurely shunting aside students or accepting society's gender, race, and class biases in its talent selection, it is acting out a self-fulfilling prophecy of demographic determinism. Using the past performance and interests of minority students in science and engineering to project an inevitable shortage in these fields, for example, is a counsel of despair. In conveying information about the ostensibly desirable social and intellectual characteristics of scientists and engineers, seasoned with the stereotypes and images that permeate American culture, the formal education system sorts many otherwise talented students out of the science and engineering pipeline.

It is clear that American schools, colleges, and universities have the capacity to provide enough qualified scientists and engineers to meet the Nation's needs. However, there is evidence that the system may not be working as well as it could. Our schools can learn to identify talent better and to nurture it with greater care. Our universities can take measures to attract and retain more talent in science and engineering. Students who now fall through the cracks can be better served—both by the formal system and by informal means. All of these approaches can lead to a larger, stronger pool of talent that reflects the variety of American society in serving its future technological needs.

The loss of a potential scientist or engineer to a career in another profession is still society's gain. We would hope that our education system would prepare students for careers that will be in demand. But the market is too unpredictable to target specific personnel needs, so the goal of education, including that for science and engineering, should be to prepare students for an uncertain future by imparting a range of skills. This means that the skills of scientists and engineers must be both specialized enough to satisfy the demands of a stable market for science and engineering faculty and industrial researchers and general enough to qualify degree-holders for special opportunities that arise farther afield from their training but grow central to the national interest.[38]

[38]A dynamic economy will create such national needs and imbalances. The best preparation for them is a malleable stock of what some economists call "human capital." See Howard P. Tuckman, "The Supply of Scientists and Engineers in an Era of Institutional and Technological Change," *Policy Research and Analysis Workshop on an Agenda for Science Policy Research* (Washington, DC: National Science Foundation, Sept. 17, 1987).