Chapter 3

Higher Education for Science and Engineering

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Chapter 3

Higher Education for Science and Engineering

DIVERSITY OF INSTITUTIONS, STUDENTS, AND DEGREES

The 3,300 universities, colleges, and engineering institutes in the United States enroll a larger proportion of young adults than in any other nation. About 12 million students are enrolled in institutions of higher education; over 2 million of these are first-time freshmen.[1] Half of these students will eventually receive bachelor's degrees. For the last three decades, 30 percent of bachelor's degree recipients (that is, about 9 percent of each high school graduating class) received their degrees in science or engineering, including social sciences. In recent years, about one-tenth of these bachelor's-level scientists and engineers have gone on to earn science or engineering doctorates.[2]

These broad patterns disguise a great deal of variation. Large research universities, small liberal arts colleges, historically Black institutions, 2-year institutions, technical institutes, and other public and private institutions of all kinds make American higher education extraordinarily diverse in size, purpose, and structure. Each type of institution provides a unique environment for developing talent and encouraging persistence in pursuit of a degree. While this chapter concerns characteristics of educational environments and their students, its emphasis is on institutions as producers of scientists and engineers at all degree levels. Of course, institutions of higher education have many other functions besides producing scientists and engineers, from vocational training to the cultivation of western civilization's artistic and cultural traditions.

Although 30 percent of baccalaureates are awarded in science and engineering, the relative popularity of different fields has shifted substantially with events in the job market of the last three decades. Increasing college enrollments, which was the trend until 1982, meant more science and engineering baccalaureate recipients; in contrast, the proportion continuing on to Ph.D. study reflects market demand, the availability of Federal research and development (R&D) funds, and direct student support (see figure 3-1).[3] There is also substantial variation in science and engineering by sex, race, and ethnicity of degree recipients. White males are far more likely to earn degrees in science and engineering than women, Blacks, or Hispanics (see figure 3-2). These differences-which vary from field to field–have narrowed in the past 15 years, but are still generally large.

Most fields of graduate study in the sciences, as distinguished from engineering, are oriented toward the academic as well as the industrial job market; somewhat less than half of Ph.D. scientists work in academic institutions. The Ph.D. is the basic professional degree in most fields of science, and most science students seek research or teaching positions. Despite growing undergraduate enrollments from the late 1960s to the early 1980s, a stagnant academic job market and slower growth in Federal research funds have left many young Ph.D.s "underutilized."[4] Many institutions, beset by a faculty

[1] Other notable statistics on the total enrolled population are that 60 percent are full-time students and two-thirds attend universities and 4-year institutions. Among first-time freshmen (who represent roughly 80 percent of high school graduates), the ratio of full- to part-time students is two to one, but equal numbers are enrolled in 2- and 4-year institutions. See U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, *Digest of Education Statistics 1987* (Washington, DC: May 1987), tables 104-110, 154. The focus of this chapter is on full-time students enrolled in America's 1,500 4-year colleges and universities.

[2] Natural sciences and engineering bachelor's degrees account for an average of 20 percent of the baccalaureates awarded during this period. National Science Foundation, *Science and Engineering Degrees, 1950-80: A Source Book*, NSF 82-307 (Washington, DC: 1982).

[3] Betty Vetter and Henry Hertzfeld, "Federal Support for Science and Engineering Education: Effect on Output of Scientists and Engineers 1945-1985," OTA contractor report, 1987. These relationships are elaborated below.

[4] The National Science Foundation adds the rates of unemployed and "underemployed"-those who are Involuntarily in conscience or engineering jobs or working part-time but seeking full-time employment—to define an "underutilized" segment of the science and engineering work force. In 1986, 6.5 percent of scientists and 2.3 percent of engineers, at all degree levels, were underutilized. National

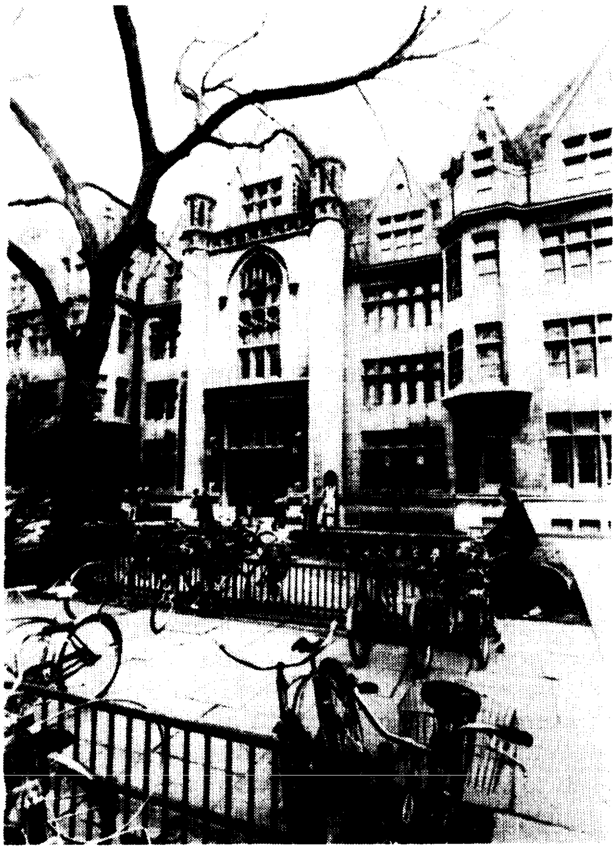


Photo credit: University of Chicago and The Chronicle of Higher Education

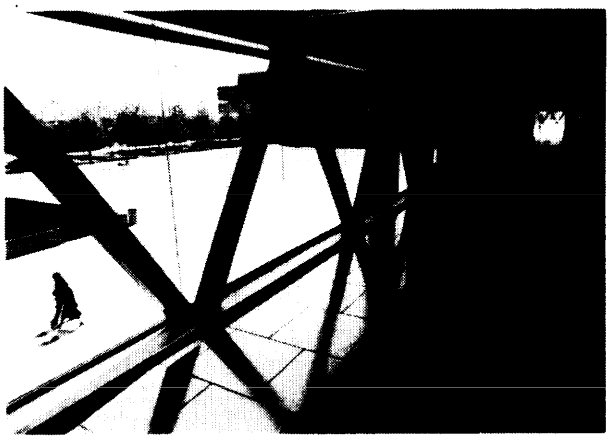
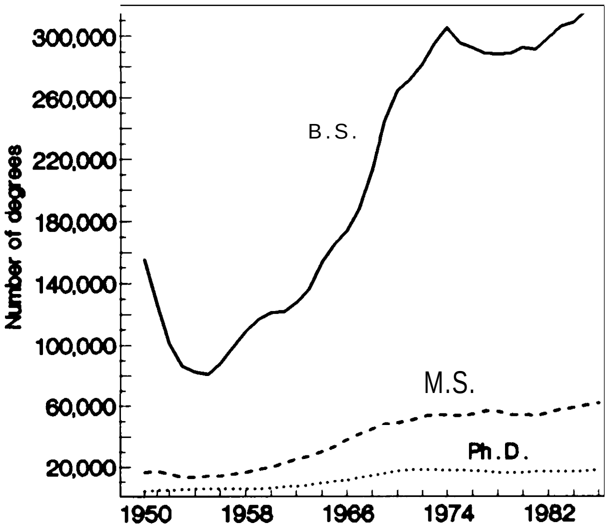


Photo credit: University of Massachusetts, Boston, and The Chronicle of Higher Education

American higher education institutions are extremely varied, ranging from internationally renowned research universities to small liberal arts colleges emphasizing undergraduate teaching. Some smaller institutions focus on local students, certain types of students (e.g., minority institutions), course offerings (e.g., engineering schools), or course structure; while others emphasize a diverse student body and comprehensive curriculum. This diversity has been a strength of American education and research training.

Figure 3-1.—Science/Engineering Degrees, by Level, 1950-86



SOURCE: U.S. Department of Education, Center for Education Statistics (B.S. and M.S.); National Research Council, *Survey of Doctorate Recipients* (Ph.D.).

tenured largely during 1960s-era expansion, curtailed their hiring in the 1970s. Full-time graduate enrollments in science and engineering have grown since the early 1970s. If not for the influx of foreign graduate students, however, these enrollment increases would have been less. Retirements and turnover of faculty in the mid-1990s, combined with a resurgence in undergraduate enrollments later in the decade, may eventually relieve these pressures.[5] Until then, the attractiveness of an academic career will pale for many students.

In engineering and some fields of science (notably earth sciences and computer science), the bachelor's or, increasingly, the master's degree is the most important professional degree. The employment markets for these fields are dominated by industry; for example, 80 percent of engineers work for private companies.[6] Unlike the Ph.D.-oriented fields, these fields respond to industrial, rather than academic,

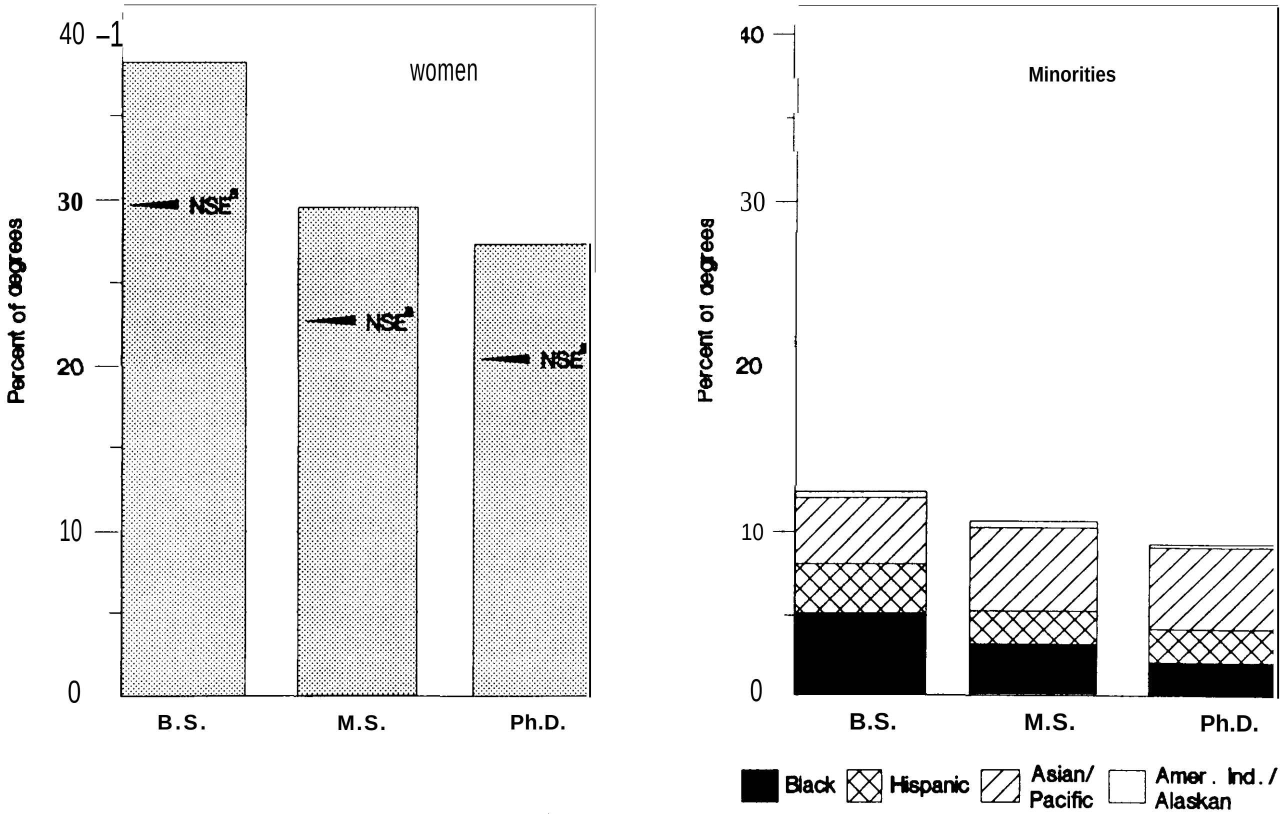
(continued from previous page)

Science Board, Science Indicators: The 1985 Report, NSB 85-1 (Washington, DC: 1986), pp. 67-68.

[5]Institutions *in the higher education system will absorb these trends in different ways. The research universities will have the most financial latitude to accommodate flux in faculty and research positions as well as student enrollments. See, for example, Harvey Brooks, "The Research University: Doing Good, and Doing It Better," Issues in Science and Technology, vol. 4, No. 2, winter 1988, pp. 49-55.*

[6]U.S. *Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," staff paper, Jan. 21, 1987.*

Figure 3-2.–Science/Engineering Degrees, by Level, Sex, and Race/Ethnicity, 1986



[a]NSE is natural science/engineering, which does not include the social sciences.

SOURCE: U.S Department of Education, Center for Education Statistics (B.S. and M.S,); National Research Council, Survey *of Doctorate Recipients* (Ph.D.)

needs. Because their periods of training are shorter, enrolled students can react more quickly to employment opportunities. These fields, not coincidentally, have been the ones that experience enrollment and employment booms, and subsequent busts. When fields boom (the most recent examples are engineering and computer science), faculty shortages develop. Foreign faculty have proven vital to maintaining teaching capacity in these fields. U.S. citizens have generally sought high-paying baccalaureate-level industrial employment rather than graduate study in pursuit of faculty positions.

Federal influence over higher education is especially forceful at the graduate level. Federal fellowships and other forms of assistance are awarded to support specific graduate students in specific fields of study. Federal R&D programs can also be highly influential, since they provide employment opportunities for researchers in universities, industry, and government, and assistantships for students. Before they aspire to research apprenticeships and careers in science and engineering, however, students must acquire undergraduate educations that prepare them for graduate study or, alternatively, convince them that research is not their destiny. The character of the undergraduate experience is usually decisive for imparting the skills and expectations needed for participation in science or engineering.

UNDERGRADUATE EDUCATION

Key Questions

- How well does undergraduate education nurture talent?
- What leverage or influence does the Federal Government have on undergraduate education?
- Are there particular undergraduate environments in science that encourage students to pursue a Ph. D.? Are certain environments particularly successful with specific groups?

Key Findings

- Interest by freshmen in science and engineering is declining slightly, while majors such as business are increasingly popular. Science and engineering students continue to have higher high school grade point averages and Scholastic Aptitude Test (SAT) scores than those entering other majors.
- Any action that increases the size or changes the composition of the entire undergraduate population, such as the G.I. bill and Title IX (which outlawed sexual discrimination), is likely to be reflected in the number of baccalaureate awards. Science and engineering fields share in these changes.
- Research universities, in absolute terms, produce the largest number of students that go on to Ph.D.s. in science and engineering. But small liberal arts and technical colleges with some active research produce, in relation to their size, a remarkable number of students who eventually earn Ph.D.s. in these fields.
- Science and engineering majors are similar to other students in their sources and extent of financial aid. Undergraduate loan burdens do not seem to affect decisions by the majority of students to pursue graduate degrees.

Higher education, once an optional route to occupational mobility, is now a necessity for those seeking admission to the professions. The baccalaureate is a crucial, but by no means final, credential for employment, while institutions differ markedly in the educations they provide. The process of recruiting and sorting student talent is reciprocal: institutions' reputations, fees, and locations influence the choices of students and their families, while the students' academic profiles guide (but do not alone determine) institutions' admissions decisions.[7] Institutions will have important effects on students' future careers, influencing their choices of majors, their friends, and their likelihoods of pursuing graduate study. But a student's career interest and planned major will also influence the choice of college. Data on the "intentions" of entering freshman capture the link between actual college enrollments —the net effect of mutual recruitment and sorting— and declared career plans.

Freshmen Intentions To Major in Natural Science and Engineering

The expressed intentions of entering freshmen indicate that fewer students today are interested in natural science and engineering majors than at the end of the last decade. In 1978, 27 percent, or about 286,000, of first-time, full-time freshmen entering the Nation's 4-year colleges and universities, planned to pursue majors in natural science or engineering. By 1986, 24 percent (246,000) expressed such interests.[8]

'Applications for admission to higher education institutions have been rising since 1986. Perhaps this is due to effective college marketing. Students seem more willing to apply to institutions that they ordinarily would consider beyond their reach academically and financially. Because the number of students available to become freshmen has been broadcast as demographically depressed, multiple applications increase the prospect of choice. See Robert Rothman, "Surprise: Freshman Enrollment Is Surging," Education Week, vol. 7, No. 7, Oct. 21, 1987, pp. 1, 21. From the institution's perspective, a multivariate "predicted performance" model that accounts for differences in the high schools from which students apply, as well as standardized test scores, grades, extracurricular activities, etc., is preferred in making admissions decisions. See Hunter M. Breland, Educational Testing Service, "An Examination of State University and College Admissions Policies," research report, January 1985.

[8] Data are from the Cooperative Institutional Research program's annual survey of freshmen in American colleges and universities. Freshmen intentions to major in fields are taken as an indicator of degree trends 4 to 5 years later. The correlation is strong and positive, but variable by field. Kenneth C. Green, "Freshman Intentions and Science/Engineering Careers," OTA contractor report, December 1987. Also note that in this section we use the more restrictive designation "natural science and engineering" (omitting social science) to estimate career interest and size of the science and engineering talent pool.

The decline has been neither steady nor consistent. Freshman interest in some majors, such as computer science and engineering, rose substantially in the early 1980s as students sought careers in high-growth fields.[4] Enrollments in both fields began to decline in 1984, however, and by 1986 their shares of freshman major intentions had slipped back to where they had been in the late 1970s. Freshmen interest in becoming research scientists also declined by more than one-quarter between 1978 and 1986. This drop in freshman interest could be interpreted as a delayed response to a market perceived as offering too few desirable positions for those graduating with degrees in science. It is a disturbing trend and an early warning signal to those concerned about replenishing the research work force.

Blacks and Hispanics represent 8 and 2 percent, respectively, of the freshmen intending majors in the natural sciences and engineering, and Asians 6 percent. Changes in the distribution of freshman preferences of Asian and Black students by broad field can be observed in table 3-1; for all broad fields of natural science and engineering, the proportion of whites declined from 1978 to 1986 while the proportions of Asians and Blacks rose. In general, Cooperative Institutional Research Program (CIRP) data indicate that science-interested freshmen are more likely than their peers in other fields to report "A" or "A-" grade point averages in high school, and to report having spent more time on high school homework. They are more confident of their abilities and have higher degree aspirations. More of these high school "high achievers," however, are choosing other majors, particularly business, than did so in the past.[10]

How well do freshmen intentions predict degree outcomes? A 1986 CIRP followup survey of the freshman cohort of 1982 shows that retention to completion of the baccalaureate varies by discipline. For example, 70 percent of freshman business majors earn the baccalaureate in business 4 years later, and over 60 percent of education and social sciences majors receive degrees in these fields. In natural science and engineering fields, the retention rates are lower, ranging from a low of 38 percent in the physical sciences to a high of 58 percent in engineering. In general, these fields lose twice as much talent to fields other than natural sciences and engineering fields than they gain. As seen in figure 3-3, the "sur-vival rate" for the 1982 freshman cohort in four broad fields can be measured in several ways. (Attrition from a natural science or engineering major, it should be remembered, can represent a gain elsewhere.) In the biological sciences, physical sciences, and engineering, 5 to 10 percent of the bachelor's

[4] Alexander W. Astin et al., *The American Freshman: Twenty Year Trends* (Los Angeles, CA: University of California at Los Angeles, Higher Education Research Institute, 1987), pp. 14-15.

[10] *When interest in natural science and engineering majors is analyzed for the high achiever student population (those with "A" or "A-" high school grade point averages), the proportion of Asians increases from 6 to 8 percent, while the proportion of Blacks decreases by half to 4 percent. Eighty-five percent of the high achiever population is white.*

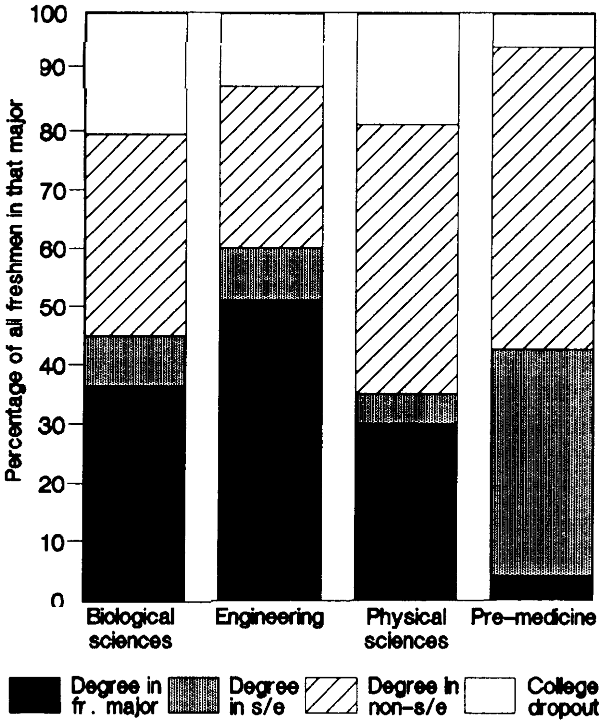
Table 3-1.—Freshman Preferences for Various Undergraduate Majors, by Selected Racial/Ethnic Group, 1978 and 1986[a]

	Asian		Black		White[b]	
	1978	1986	1978	1986	1978	1986
Natural science and engineering						
Physical sciences	1.9	4.5	6.0	10.3	91	83
Biological sciences	0.9	6.3	5.8	6.4	91	84
Pre-medicine	2.9	7.4	7.9	9.9	87	79
Engineering	2.2	5.8	6.8	7.4	89	84
Other majors						
Social sciences	0.9	2.2	12.6	9.8	84	85
Arts & humanities	0.9	2.2	6.3	6.2	91	90
Business	0.9	2.0	9.8	11.3	88	85
Education	0.5	0.6	8.5	6.5	90	91
All other[c]	1.1	2.9	8.8	9.4	88	86

[a] Freshmen of selected racial/ethnic group as a percentage of all freshmen planning to pursue majors in selected fields.
[b] Percentages have been rounded.
[c] Includes nursing, allied health, architecture, and undecided students, among others.

SOURCE: Kenneth C. Green, "Freshman Intentions and Science/Engineering Careers," OTA contractor report, 1987,

Figure 3-3.—Natural Science/Engineering B.S. Degree Attainment, by Freshman Major, 1982 Freshmen



SOURCE: Kenneth C. Green, OTA contractor report, 1987. Based on data from the Cooperative Institutional Research Project, University of California at Los Angeles.

recipients earn a degree in a field other than the freshman major but still within the natural sciences and engineering.

Trends in Science and Engineering Baccalaureates

The number of science and engineering baccalaureates has risen slightly as a percentage of the 22-year-old population, although its share of all baccalaureate degrees awarded has been fairly constant during the past two decades. The distribution of these degrees by field has varied considerably in response to economic developments, Federal and State policies, and social attitudes (see figure 3-4). Physics degrees fell during the 1970s and are still recovering; one-third of physics graduates continue with graduate study. With earth scientists in surplus owing to the decline in the petroleum and mining industries, baccalaureates in these fields have been declining sharply since 1982. A decline in mathematics baccalaureates in the late 1970s was accompanied by a rise in computer science degrees; mathematics is now rebounding somewhat. Degrees in biology have been declining in the past 10 years. Baccalaureates in the social sciences peaked in 1974, after a period of substantial growth, and have been declining ever since.[11]

Women in Science and Engineering

Women have never been well represented[12] among recipients of science and engineering baccalaureate degree awards (see figure 3-5). Women received about 38 percent of science and engineering bachelor's degrees (heavily concentrated in the social sciences (43 percent) and life sciences (44 percent)) in 1986.[13] Although women have made gains across the board in their share of science and engineering baccalaureates, since 1984 their share has leveled off, and in computer science, engineering, biological sciences, and the physical sciences is declining slightly.[14] Yet CIRP reports that in 1986 women were twice as likely as men to be interested in medical careers (often anchored by an undergraduate major in biology) and significantly more likely to be interested in research.[15]

[11] Betty M. Vetter and *Eleanor L.* Babco, *Professional Women and Minorities: A Manpower Data Resource Service, 7th ed. (Washington, DC: Commission on Professionals in Science and Technology, December 1987), pp. 137,* 151, *199.*

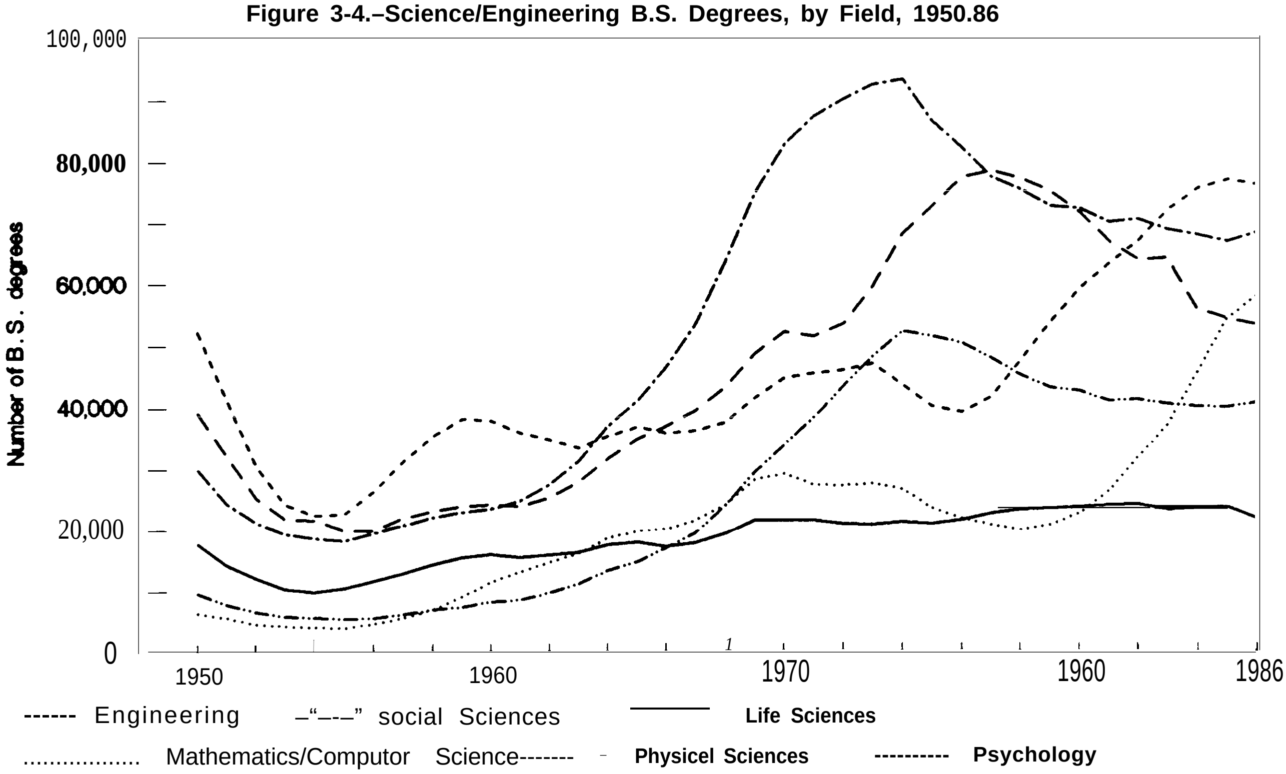
[12] The *widespread use of the terms "underrepresented" and* "over-*represented" is troublesome. Both terms assume some "normal" level* of representation *relative to a base population. That population could be the total U.S. population, the size of the college-age (18-to* 24-year-olds) *cohort, or the number of undergraduate students enrolled. The referent is seldom clear; the terms are not used throughout this report. For further discussion, see U.S. Congress, Office of Technology Assessment, Elementary and Secondary Education for Science and Engineering-A Technical Memorandum, forthcoming, summer 1988.*

[13] Vetter and Babco, op. *cit., footnote* 11, p. 54.

[14] Betty *M.* Vetter, *"Women's Progress," Mosaic, vol. 18, No. 1, spring 1987, pp. 4-5.*

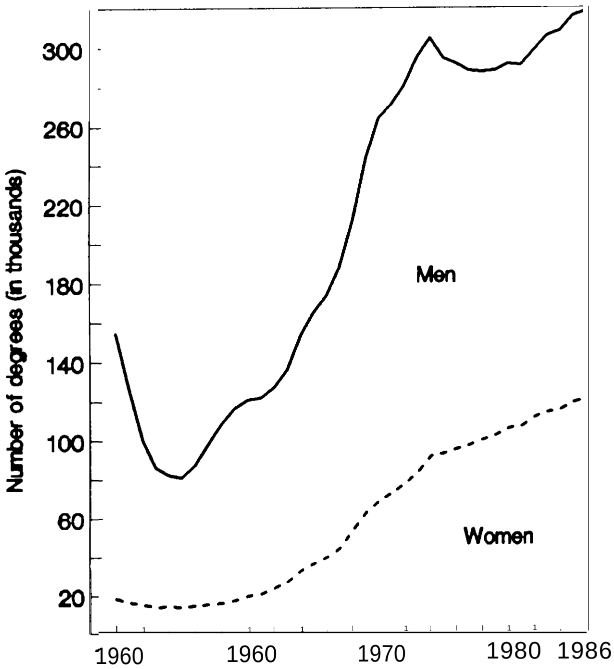
[15] Green, *op. cit., footnote 8. The gap between aspirations and realization has been explained by some as a "chilly climate" for women that still prevails in many college classrooms. Roberta M. Hall and* Bernice *R. Sandier, The Classroom Climate: A Chilly One for Women? (Washington, DC: Association of American Colleges, Project on the Status and Education of Women, 1982); Roberta M. Hall and Bernice R. Sandier, Out of the Classroom: A* Chilly *Campus Climate for Women? (Washington, DC: Association of American Colleges, Project on the Status and Education of Women, October 1984). In terms of the thinning ranks of the research work force noted earlier, women's intentions, at least as they enter college, would appear to be a welcome antidote, if degree-taking indeed follows.*

Figure 3-4.–Science/Engineering B.S. Degrees, by Field, 1950.86



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

Figure 3-5.—Science/Engineering B.S. Degrees, by Sex, 1950-86



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

The implicit assumption that scientific competence in the United States is disproportionately concentrated in the 40 percent of the population represented by white males is, as one observer puts it, "a handicap that neither science nor the U.S. can any longer tolerate on economic, competitive, moral, or any other grounds."[16] Yet the gender gap in recruitment to and participation in science, reduced by two decades of gains, is in danger of widening again.[17] By now, however, strategies targeted to increase the recruitment and participation of women in science and engineering are well known (see box 3-A).[18]

[16] Michael Heylin, "Women, Minorities, and Chemistry," *Chemical & Engineering News*, vol. 65, No. 37, Sept. 14, 1987, p. 3.

[17] Betty Vetter, "Women in Science," *The American Woman 1987-88: A Report in Depth*, D. Shavlik and J. Touchton (eds.) (Washington, DC: Women's Research and Educational Institute, 1987).

[18] Elizabeth K. Stage et al., "Increasing the Participation and Achievement of Girls and Women in Mathematics, Science, and Engineering," *Handbook for Achieving Sex Equity Through Education*, Susan S. Klein (cd.) (Baltimore, MD: The Johns Hopkins University Press, 1985), pp. 237-268. Also see Susan S. Klein, "The Role of Public Policy in the Education of Girls and Women," *Educational Evaluation and Policy Analysis*, vol. 9, No. 3, fall 1987, pp. 219-230.

Photo credit: National Institutes of Health

Females interested in scientific careers have faced strong opposition ever since science became an organized and academic activity. Slowly, the barriers to their participation are being eroded, but there are many signs that women's progress has, for the moment at least, sputtered. Renewed efforts among the existing scientific work force are needed to make science more attractive to females.

Minority College Attendance and Degree-taking in Science and Engineering

Although they constitute about 12 percent of the population (and 9 percent of the college freshmen), Blacks receive only 2.6 percent of the bachelor's degrees and 2 percent of the doctorates in science and engineering.[19] The proportion of Blacks that complete high school has increased from 10 to 70 percent in the last 40 years. Black enrollments in higher education have increased accordingly (although they are now declining, perhaps because of shifts in Federal aid from grants and scholarships to loans, which Blacks are often reluctant to assume).[20] Two-thirds of Blacks enrolled in higher education are female. Black males are shunning higher education, a talent loss of increasing proportions. Some of this loss is to the Armed Forces, which are excellent providers of technical training and also promise financial support for higher education following a period of service.[21]

[19] *A. K. Finkbeiner, "Demographics or Market Forces?" Mosaic, vol. 18, No. 1, spring 1987, p. 17.*

[20] *There are no national data to link firmly this cause with this effect, and the phenomenon may preclude the collection of information, for example, in the Department of Education's Recent College Graduate survey. See Applied Systems Inc., "Student Borrowing, Starting Salaries and Education Debt Burdens: Evidence From the Surveys of Recent College Graduates," OTA contractor report, September 1987, and discussion below.*

[21] *Slogans such as the Armed Forces' "It's a great place to start!" apparently have great appeal. In 1985, over 90 percent of Blacks who enlisted were high school graduates. Solomon Arbeiter, "Black Enrollments: The Case of the Missing Students," Change, vol. 19, No. 3, May/June 1987, p. 17. "No equivalent exists in higher education to*

Box 3~A.—Recruiting Women to Science and Engineering: One Physicist's Prescription

A female physicist's observations on recruiting women to careers in science and engineering form a kind of primer on women's participation:[1]

- Positive role models, e.g, the national impact of Sally Ride, cannot be emphasized enough. "In addition to seeing women functioning as scientists and engineers on the job, students also use role models as a primary source of reassurance that a technical career can be mixed with family responsibilities. "
- In any science-related activity, a "reasonably sized female peer group" provides a "critical mass. " This is essential at the "most critical times when large numbers of girls turn away from considering technical careers," junior high school and at the end of the sophomore year in college, "when they are selecting a major. "
- We forget that "today's culture still takes men *more* seriously" than women.

An agenda for action requires that women in science receive national attention in the form of publicizing statistics on the gap between the sexes in participation in science,

- "Newspaper editors and television producers can insist that women appear with men in news items about science and technology. "
- Scholarships and internships especially for women can be offered by government agencies, academic institutions, and high-technology companies.
- The National Science Foundation can be authorized to study "the on-campus factors thought to be important in the recruitment and retention of women in science and engineering majors. "
- Summer programs for high school girls can bring them to university campuses to take courses and learn about technical careers. This would be a kind of national "Science Head Start" program that Congress could delegate to the States.
- Through cooperative efforts between educational institutions and prospective employers, the alumni of these summer programs could be hired for summer jobs.

National policy, however, can be developed to support women once they enter the science and engineering work force. Among the issues that Congress should consider are these four:

1. Guidelines on maternity and paternity leave;
2. Flexible working hours, job-sharing, and home- as well as office-centered work;
3. Public and private day-care facilities of great variety; and
4. Research on interrupted careers.

These issues suggest actions that change the culture through legislation. Only the enforcement of legislation will change individual attitudes.

[1]Most of the following text IS a paraphrase of Elizabeth S. Ivey, "Recruiting Mm-e Women Into Science and Engineering," *Issues in Science & Technology*, vol. 4, No. 1, fall 1987, pp. 84-86. Direct quotes are Indicated.

There have been important shifts in the institutions that Black students attend. The historically Black colleges and universities (HBCUs)[22] have been the main source of Black scientists and engineers (see box 3-B), followed by the large State universities. Most Blacks enrolled in 4-year institutions are now in traditionally white universities.[23]

the enormously successful 'Be All That You Can Be' campaign for military recruitment. " 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).

[22]Historically *or traditionally Black institutions refer to 105 colleges and universities so designated in 1976 by the National Center for Education Statistics and founded before 1954 for the purpose of educating Black students. These institutions are located in 19 States and the District of Columbia. Of the 100 in existence in 1984, 57 were privately controlled; the rest are under State control. Susan Hill, The Traditionally Black Institutions of Higher Education, 1860-1982 (Washington, DC: U.S. Department of Education, 1984),* p. *xi.*

[23]Walter R. Allen, "Black Colleges *vs. White Colleges: The Fork in the Road for Black Students," Change, vol. 19, No. 3, May/June 1987, p. 28; Stephen Chaikind, College Enrollment Patterns of Black and White* Students *(Washington, DC: DRC, 1986); Scott* Jaschik, *"Major Changes Seen Needed for Colleges to Attract Minorities," The Chronicle of Higher Education, vol. 34, No. 13, Nov. 25, 1987, pp.* A1, 31.

Box 3-B.–The National Institutes of Health Minority Access to Research Careers Program[1]

Established in 1975 by the National Institutes of Health (NIH), the Minority Access to Research Careers (MARC) Program focuses on increasing the number and research capabilities of minority scientists in biomedical fields and in strengthening science curricula at minority institutions. The object is to prepare students for careers in biomedical research. The explicit focus of the program is on improving minority students' opportunity, aspiration, and preparation for graduate study. The MARC Program offers both institutional training grants and individual fellowships: the Faculty Fellowship, the Visiting Scientist Award, the Honors Undergraduate Research Training Grant, and the Predoctoral Fellowship.

The Faculty Fellowship, the first award offered, provides opportunities for advanced research training for faculty from 4-year institutions serving predominantly minority students. Members are nominated by their institutions and may serve up to 3 years. The Visiting Scientist Award provides financial support for outstanding scientist-teachers at such colleges and universities in the hope of strengthening research and teaching in the biomedical sciences. Stipends are set on a case-by-case basis, and funding can be requested for a period from an academic quarter to 1 year. The Honors Undergraduate Research Training Grant, initiated at the suggestion of Congress and the largest component of MARC, often works in conjunction with NIH's Minority Biomedical Research Support Program. Its objective is to increase the number of well-prepared students who can compete successfully for entry into graduate biomedical programs. Training support is offered for a maximum of 5 years to carefully selected undergraduate honors students at institutions in which enrollments are drawn primarily from minority groups. The Predoctoral Fellowship, also awarded for a maximum of 5 years, targets the honors graduates and is conditional on acceptance into a biomedical Ph.D. program.

MARC provides tuition and stipend support for third and fourth year honors undergraduate students. Its specially structured curriculum includes exposure to ongoing research in the biomedical sciences, travel, administrative support, equipment purchase, and research, including summer study. From 1977 to 1984, MARC Honors has grown from $990,000 (or $700,000 in 1972 dollars) (74 trainees at 12 schools) to $4.9 million ($2.2 million in 1972 dollars) and 366 undergraduate trainees at 56 schools). Results of a 1984 evaluation and survey showed that the program was successful in keeping talented minorities in school and encouraging them to pursue research careers.

The MARC Program is continually monitored by a review committee. Site visits show that faculty members report high motivation among MARC honors students and note several examples of published research. A questionnaire sent to more than 800 former trainees indicates that three of four have enrolled in graduate or professional programs. Some critics contend that the MARC Program places too much emphasis on preparing students for research careers and ignores those with other career plans. Yet most (63 percent) MARC alumni are employed in science or engineering fields.

The institutional impact of the various MARC Programs is indicated by a definite increase in biology bachelor's degrees at MARC schools. In addition, student surveys show that the research component of the program is consistently touted as the most appealing aspect. Many maintain that they would not have continued their studies had it not been for the availability of MARC funds and the opportunities fostered by the program. The creation of role models in these graduate programs encourages the program's continued success.

[1]Howard H. Garrison and Prudence W. Brown, *Minority Access to Research Careers: An Evaluation of the Honors Undergraduate Research Training Program* (Washington, DC: National Academy of Sciences, Institute of Medicine, Committee on National Needs for Biomedical and Behavioral Research Personnel, 1985).

HBCU enrollments and degree awards are declining, and the large State universities are not compensating for the downturn. Half of all Black students who attend college enter higher education in 2-year or community colleges. It is likely that these institutions place tiny numbers of their graduates into the science and engineering pipeline of 4-year colleges.[24]

[24]*According to a survey of 1980 high school graduates, Asian-American students were twice as likely (American Indian and white students 1½ times as likely) as Black and Hispanic students to enter 2-year colleges and later transfer to 4-year institutions. For all groups,*

Photo credit: National Institutes of Healfh

While most Blacks in science and engineering used to come from the historically Black colleges and universities, such as Howard University in Washington, DC, an increasing proportion now enroll in traditionally white universities, including community colleges. Overall, Black enrollment in science and engineering is declining.

Most Hispanics and American Indians in higher education are enrolled in 2-year colleges. The Hispanic population is heavily concentrated in California, Texas, New York, and Florida. About 75 colleges and universities have enrollments that are over 25 percent Hispanic.[25] Institutions such as the University of Texas-El Paso, Florida International University, and the University of New Mexico have graduated large numbers of Hispanic students.[26]

Asian-American students, who are variously of Chinese, Korean, Indochinese, Filipino, Japanese, Laotian, Cambodian, Indian, and other origins, continue to do very well educationally, especially in science and engineering. One indicator of achievement is that 70 percent of Asian-American 18-year-olds take the SAT as compared to 28 percent of their age peers. Asian-Americans also tend to concentrate at top-ranking universities. The freshman classes of the Massachusetts Institute of Technology, the California Institute of Technology, and the University of California at Berkeley in the fall of 1986 were over 20 percent Asian-American, compared to 3.1 percent of all freshmen nationwide[27] (see box 3-C).

(continued from previous page)

there is a flow (of one-third to one-half as many students) in the other directions as well. See Shirley Vining Brown, Minorities in the Graduare Education Pipeline, Research Report of the Minority Graduate Education Project (Princeton, NJ: Graduate Record Examinations Board and Educational Testing Service, 1987), p. 5. Although no systematic field-level data are available, third-year transfers into engineering are reportedly not uncommon when an engineering institution is in close proximity to 2-year colleges that can feed it students (OTA Workshop on Engineering Education in 1997, Sept. 9, 1987; Bernard Sagik, personal communication, October 1987).

[25] *The Chronicle of Higher Education, "Hispanics: Some Basic Facts," Sept. 16, 1987, p. A36. In 1987, 60 U.S. Institutions founded the Hispanic Association of Colleges and Universities. Based on a criterion of at least 25 percent Hispanic enrollment, 100 institutions arc expected to qualify by the year 2000. See Cheryl M. Fields, "Demographic Changes Bring Large Hispanic Enrollments to Over 60 Institutions," The Chronicle of Higher Education, Oct. 7, 1987, p. A40.*

[26] *Richard C. Richardson, Jr. et al., "Graduating Minority Students," Change, vol. 19, No. 3, May-June 1987, p. 24.*

'Evidence of the superior academic performance of Asian-American students has been described recently in Time, the Sunday New York Times Magazine, and the Los Angeles Times Magazine in stories alleging discrimination against Asian-American students in admissions to U.S. colleges and universities, and their perception as a "nondisadvantaged" minority. See Green, op. cit., footnote 8; Manpower Comments, vol. 24, No. 10, December 1987, pp. 14-15.

Box 3-C.–Asian-Americans in Science and Engineering: Perceptions and Realities

Stereotypes abound about the intelligence and educational achievements of Asian-American children. A closer look suggests that reality is far more complicated than perceptions, though a lack of research on the interaction of country of origin, social class, and family structure with educational success inhibits understanding of Asian-American participation in the science and engineering work force.

The whiz-kid image fits many of the children of Asian immigrant families who arrived in this country in the late 1960s and early 1970s, following passage of a 1965 law liberalizing immigrant quotas. Most of these immigrants came from Hong Kong, South Korea, India, and the Philippines. And the image fits many children of the more than 100,000 Indochinese (primarily Vietnamese) immigrants who arrived in this country following the end of the Vietnam War in 1975.[1]

Both of these groups included mostly middle- to upper-income professional people who were fairly well-educated and who passed onto their children an abiding interest in education and a strong work ethic.

For thousands of other Asian-Americans–a high percentage of the 600,000 Indochinese refugees who fled Vietnam, Laos, and Cambodia in the late 1970s—the problems are far different. Many of this recent wave of refugees lived in poor surroundings in their homelands. They came to the United States with few skills and little English, have a tough time finding a decent job, and often share housing with relatives. Their children find it difficult to learn; some are attracted to drugs and gangs; many drop out of school.

There may be both a generational and a class factor influencing Asian-American students' orientation to education. There is also a geographical dimension: over one-third of Asian-Americans reside in California and another 22 percent in Hawaii and New York combined.

Asian-American college-bound seniors have the highest high school grade point averages and degree aspirations. They do especially well in mathematics courses, which may account more than their verbal or social skills for their attraction to science and engineering. Asian-Americans take more, and score higher on, Advanced Placement examinations offered in science and mathematics. They also excel in the mathematics portion of the Scholastic Aptitude Test. In 1985, Asian-American college-bound seniors were twice as likely as other students to plan an undergraduate major in engineering.[2] Because their preparation is better and their attrition less than other groups, Asian-American students succeed in higher education at all degree levels.

In 1986, there were over 225,000 Asian-American scientists and engineers representing about 5 percent of the total science and engineering work force, compared to 2 percent of the overall U.S. work force.[3] The Asian-American contribution to U.S. science and engineering is indisputable. But no single ethnic group will compensate for the declining numbers of white students planning careers in science and engineering, despite the growth in minority populations over the next two decades.

As for the perception of Asian-American students, the words of a resource teacher with the St. Paul, Minnesota, school system's Multicultural Center are instructive:

> We encourage our teachers not to look at minority children as having to fit into one mold. Instead we try to point out that each child brings to the classroom a different set of cultural characteristics—differences in values, in home life, in economic circumstances.[4]

Once these immigrant groups assimilate, it is uncertain how the differences we now observe will be sustained, and what will affect their future educational achievements, including their contributions to American science and engineering.

[1] This and the quotes *that follow are from* Bill *Fischer, " 'Whiz Kid' Image Masks Problems of Asian Americans," NEA Today, vol. 6, No. 8, March 1988, pp. 14-15.*

[2] *National Science Foundation, Women and Minorities in Science and Engineering,* NSF88-301 *(Washington, DC: January 1988), pp. 43-45.*

[3] Also, *in 1985, over 34,000, or 8 percent, of employed doctoral scientists and engineers were Asian; one-third of them were* non-U.S. *citizens. For other field, labor market, and career pattern comparisons see ibid., pp. 22-24 and appendix tables.*

[4] *Fischer, op. cit., footnote 1, p. 15.*

PRODUCTIVE ENVIRONMENTS–UNDERGRADUATE ORIGINS OF SCIENTISTS AND ENGINEERS

Variety among higher education institutions distinguishes the United States from other countries an contributes enormously to the education system's success and ability to reach so many students. Institutions include vast State universities and colleges (obliged to admit qualified resident high school graduates), engineering institutes akin to industrial training schools, and research universities of international repute. Private liberal arts colleges, historically Black institutions, and an array of others complete the picture.

Each type of institution serves a different clientele and has a particular local, State, or national context. Community colleges, predominantly county-based, train skilled workers and serve, for a few, as stepping stones to full baccalaureate programs. Liberal arts colleges are rooted in the classical notion that exposure to the great books and works in all disciplines is the way to instill democracy and higher-order thinking in the citizenry.

Institutions also vary in their relative emphasis on teaching and research, and on undergraduate and graduate teaching. One group of institutions, research universities, specializes in research and graduate teaching. Another group, a subset of the liberal arts colleges, specializes in undergraduate education, but does research as well. Some institutions are oriented primarily or exclusively to certain populations such as Blacks or women. Each type of institution, with its unique role, contributes to the strength of the entire higher education system.

There is competition among types of institutions and within the types themselves. Institutions compete for Federal and industry research funds, for talented students and faculty, and for equipment and facilities support. Most science and engineering undergraduates are produced by the major research universities, State institutions, and the private liberal arts colleges. From the point of view of the future science and engineering research work force, an important measure of the success of the education provided by these environments is the number of their graduates that go on to earn Ph.D. s in science and engineering.

Graduates who later earn Ph.D.s in science and engineering come from a limited number of undergraduate institutions. Ranked by the absolute number of their alumni that later receive Ph.D.s in science and engineering, 100 schools supply 40 percent of all students who receive doctorates. Four out of five of these top 100 undergraduate institutions are private. [28] Of these institutions, large degree-granting institutions (the "research universities") have the highest output of bachelor's graduates who go on to earn science and engineering Ph.D.s.

A group of about 50 private liberal arts colleges, however, has claimed to be especially productive, and accordingly, deserving of funding for research equipment and teaching.[29] These "research colleges" claim that their traditional small scale, emphasis on research experiences for undergraduates, and focus on individual students are major contributors to the eventual production of Ph.D.s in science and engineering.[30] For example, their students are encouraged to work with faculty members on current scientific research and to become full participants in research teams. A subset of this group, such as Bryn Mawr, Mt. Holyoke, and Smith, focuses on educating women and claims to be particularly productive of female scientists.

By looking at an estimate of the proportion of each institution's baccalaureate graduates in all fields that have gone on to gain Ph.D.s in science and engineering, OTA finds that some liberal arts colleges as well as universities that specialize in technical education are unusually productive of future Ph.D. scientists and engineers, when allowance is made for the size of these colleges (see figure 3-6). A large proportion of the graduates of these environments also subsequently join the research work force.[31]

[28] This *finding is based on an analysis of four baccalaureate cohorts dating from academic years 1950-51 to 1965-66. Degree totals were extracted from the Center for Education Statistics' annual Earned Degrees Conferred, and linked to the National Research Council's Doctorate Records File to calculate institutional productivity rankings through* 1979. A 10-year lag from baccalaureate *to Ph.D. award was used to create this indicator of institutional* productivity. *The methodology and various rankings are contained in Betty Maxfield, "Persistence in Higher Science and Engineering (S/E) Education: S/E Baccalaureate to S/E Doctorate Productivity of U.S. Baccalaureate-Granting Institutions,"* OTA *contractor report, September 1987.*

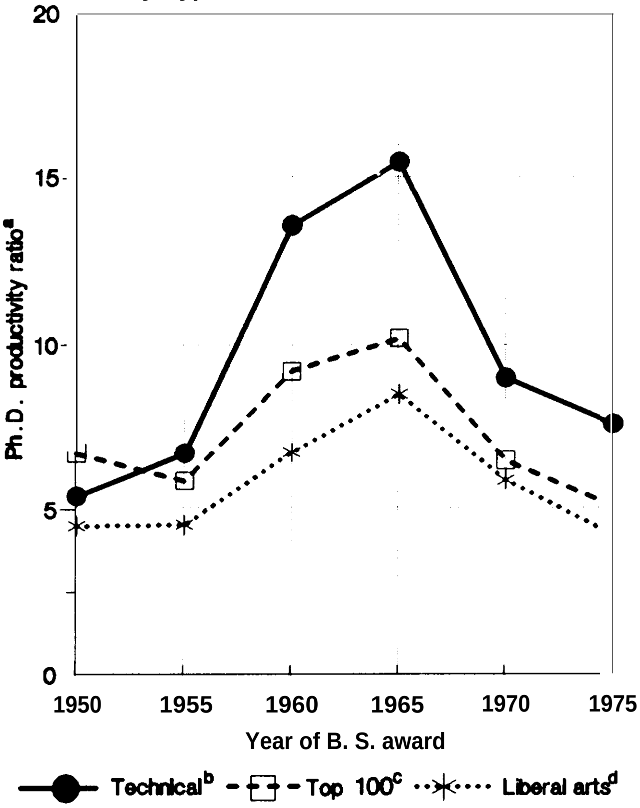
[29] In *1985, these colleges undertook a self-study:* David Davis-Van Atta *et al., Educating American Scientists: The Role of the Research College (Oberlin, OH: Oberlin College, May 1985). A* Second *National Conference on "The Future of Science at Liberal Arts Colleges" in 1986 resulted* in *another report: Sam C. Carrier* and David Davis-Van Atta, *Maintaining America's Scientific Productivity: The Necessity of the Liberal Arts Colleges (Oberlin, OH: Oberlin College,* March 1987). *Together, they are known as the Oberlin Reports. Although the labels "research colleges" and "science intensives"* have *been applied,* they *are not embraced even by members of the 50 colleges. Also, another 50 colleges probably share the characteristics of* those included *in the Oberlin Reports (see app. A).* Thus, OTA's *use of the term "research colleges" refers to about 100 private liberal arts colleges* where, historically *(and ironically), teaching has been especially valued.*

[30] A *quarter-century ago, liberal arts colleges were found to* be *among the 50 most productive institutions of higher education.* R.H. *Knapp and* H.B. *Goodrich, "The Origin of American* Scientists" *Science, vol. 133, May 1951, pp. 543-545. This finding* was *later confirmed by* M.E. Tidball *and V. Kistiakowsky, "Baccalaureate Origins of American Scientists and Scholars," Science,* vol. 193, *August* 1976, *pp. 646-652.*

[31] During *the 1970s, when single-sex colleges* either *merged or* began *admitting sizable numbers of students of the opposite sex, 2 percent of women baccalaureates from coeducational institutions went on for a science or engineering Ph.D. compared to 10 percent of the graduates of women's colleges. See* M.E. Tidball, *"Baccalaureate Origins of*

(continued on next page)

Figure 3=6.—Science/Engineering Ph.D. Productivity, by Type of B.S.-Institution, 1950-75



[a]Percent of all B.S. graduates who later got science/engineering Ph.D.s. 'he bulge in science/engineering Ph.D. productivity tracks the increase in Federal fellowship (and R&D) spending during the 1980s.
[b]Fifteen institutions with an emphasis on science/engineering and that 'end a large proportion of their students on to science/engineering Ph.D.s.
[c]The 100 institutions of all types that have the highest productivity ratios 'or science/engineering Ph.D.s.
[d]The 50 liberal arts colleges that participated in the Second National Conference on "The Future of Science at Liberal Arts Colleges" at Oberlin, June 1988. These colleges are also known as "research colleges" due to their emphasis on undergraduate and faculty research.

SOURCE: Betty D. Maxfield, OTA contractor report, 1987.

Figure 3-6 also reveals a peak in the 1960s that can be traced (see below) to the sharp rise in Federal fellowship and academic research finding in the early 1960s, followed by decline from the late 1960s into the 1970s. The bulge in baccalaureates going on for science and engineering Ph.D. s appears in all types of institutions, but is pronounced in the research-oriented ones and those receiving the most Federal dollars.

The quality of students recruited and enrolled in an institution, of course, is related to the number and quality of those who emerge with baccalaureate degrees. The education provided by the research colleges is very costly; most of the costs are borne by students and their families.[32] These colleges are highly selective in admitting students, but make great efforts to ensure students' success by offering considerable personal attention and support. The institutional environment clearly matters.[33] Elements of students' experiences in the research colleges that encourage pursuit of the Ph. D., such as early research experience, the emphasis that such schools place on teaching, and their small student-faculty ratios, could be replicated at other institutions.[34] OTA concludes that to increase numbers of Ph.D. scientists and engineers, it would be worth studying techniques used by research colleges and encourage other institutions to adopt similar strategies and values.

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Recent Natural Science Doctorates, ''Journal of Higher Education, vol. 57, No. 6, November/December 1986, pp. 606-620. In the analysis reported here, total baccalaureate output, not numbers of males and females separately, defined the productivity of institutions. Except for the predominantly women's colleges, OTA has not determined which institutions sent large numbers of women on for Ph.D.s; only the top Ph.D. producers for both sexes combined have been identified. (Elizabeth Tidball, personal communication, Dec. 16, 1987.) Also note that the predominantly women's colleges and historically Black colleges and universities serve more homogeneous populations than other types of institutions. Numerical comparisons with coeducational, largely white institutions do not capture this special kind of productivity. See, for example, Michael T. Nettles et al., "Comparative and Predictive Analyses of Black and White Students' College Achievement and Experiences," Journal of Higher Education, vol. 57, No. 3, May-June 1986, pp. 289-318. Institutional-level measurement is at best a crude proxy for the climate that fosters educational success of those who experience it, and perhaps contributes to students' later persistence to the Ph.D.

"Carrier and Davis-Van Atta, *op. cit., footnote 29.*

[33]Robert S. Eckley, *"Liberal Arts Colleges: Can They Compete?" The Brookings Review, vol. 4, No. 4, fall 1987, pp. 31-37. Not only is there lack of agreement on the definition of and criteria for measuring student "quality," but ". . . there are no detailed and comparable national data on student performance at the postsecondary level. At best, only crude estimates can be made of the quality of subgroups in the graduate talent pool by examining trends and characteristics of the applicants taking such tests as the GRE [Graduate Record Examination]." Brown, op. cit., footnote 24, p. 7. Also see* T.W. Hartle, *"The Growing Interest in Measuring the Educational Achievement of College Students," Assessment in American Higher Education, C. Adelman (ed.) (Washington, DC: U.S. Department of Education, 1986).*

[34]Alexander W. Astin, *Four Critical Years (San Francisco, CA: Jossey-Bass, 1977), esp. pp. 44,89. These elements are central to some other highly productive (small technical) institutions such as Harvey Mudd and the California Institute of Technology. Like the Massachusetts Institute of Technology and other research universities, these institutions emphasize undergraduate research, indeed often require a research thesis for graduation. See, for example, Janet Lanza, "Whys and Hews of Undergraduate Research, " BioScience, vol. 38, No. 2, February 1988, pp. 110-112.*

ENGINEERING EDUCATION

Key Questions

- How well does the preparation of new engineering graduates satisfy the needs of industry?
- What are the effects of the huge rise in the number of foreign graduate students on engineering employment and engineering teaching?
- Why, after more than a decade of growth, has the participation of women in engineering begun to decrease in the last few years?
- What effects have changing enrollments in computer science had on universities and on employment markets?
- What role does and might the Federal Government have in engineering education?

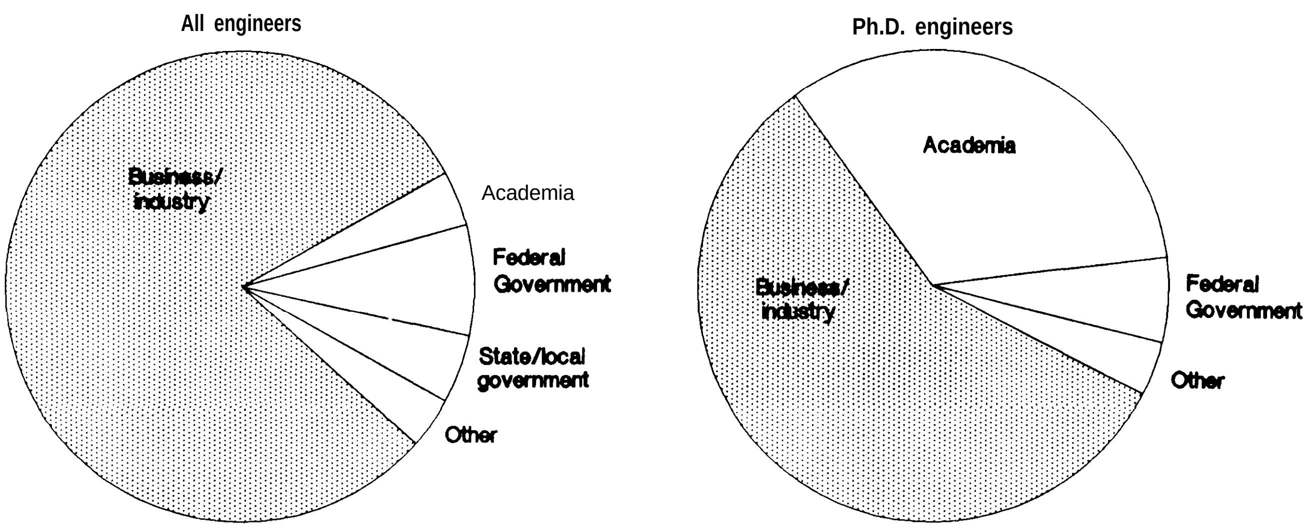
Key Findings

- Most engineers are employed in industry. Industrial demand—both civilian and defense—for baccalaureate engineers is a powerful magnet drawing students into engineering programs.
- The existing stock of engineers and technicians is versatile and can adapt its skills, but at a cost to employers and educational institutions alike.
- Engineering education needs to balance the curricular tug-of-war between the practice-oriented pull of industry and the research- and analysis-oriented push of universities.
- The complexity and cost of equipment for teaching engineering is high and rising dramatically, and many engineering schools are unable to keep up.
- Foreign graduate students have been attracted by the quality of American engineering education and have compensated for the dearth of U.S. citizens who are interested in graduate school.
- The increasing national attention to competitiveness portends an increasing Federal role in engineering education.

Engineering differs radically from science. As a profession, it is more oriented to business and problem-solving, it is highly sensitive to technological change, and it accepts the baccalaureate as the first professional degree. All these differences shape the engineering education system and its curriculum. Because students are trained for professional practice, engineering curricula normally must be accredited by the Accreditation Board for Engineering and Technology.

About 80 percent of engineers are employed in industry (see figure 3-7). Even at the high school level, employment considerations, especially per-

Figure 3-7.–Where Engineers Work, 1986



SOURCE: National Science Foundation, Science Resources Studies, Science *and Engineering Personnel*.

ceived entry-level salary, may play a larger role in students' career intentions than they do in the plans of those intending to major in science.[35] These same factors, along with engineering's acceptance of the baccalaureate instead of the doctorate, make the engineering education system particularly responsive to changes in the job market. That system can accommodate large curricular changes and shifts of interest, both in the absolute size of demand and in the balance between different fields, over periods of 3 to 5 years.

Engineering and computer science have been the fastest growing areas of study in science and engineering since the early 1970s. Engineering bachelor's degrees rose from 4.5 to 8 percent of all bachelor's degrees between 1975 and 1985.[36] Engineering schools' ability to accomplish this doubling of production has been impressive. Growth in these fields has now stopped, as the job market (particularly in the electronics and computer industries) has lost some of its steam, and as the supply of 18-year-olds has begun to decline.

The master's degree has long been an important final degree for engineering; seven times as many master's degrees are awarded in this field as Ph.D.s.[37] Especially when it involves business and managerial components, the master's is becoming a valued professional degree. Meanwhile, engineering doctorates, in decline since their peak in the early 1970s, have increased over the past few years, largely because of the influx of foreign graduate students into U.S. engineering schools.[38]

Industrial and academic demand for Ph.D.s in engineering is strong. Yet there is pressure to create separate research and teaching streams in graduate school, for the doctoral route feeds two different employment markets: industrial R&D and university faculty. After a downturn in the 1970s, engineering Ph.D. awards are slowly rising, but represent less than 20 percent of all Ph.D. awards in science and engineering.[39]

Balancing Analysis and Practice in Engineering Curricula

Engineering enrollments and market demand aside, many see weaknesses in engineering curricula and teaching methods. There has always been a tug-of-war between industry's focus on immediately applicable skills and the university's commitment to fundamental knowledge and understanding. There is some evidence that engineering education has been skewed by the pattern of Federal research funding in the 1960s. Critics have charged that the research culture of engineering schools emphasizes theory and research, failing to teach solutions to problems of design, production, and manufacturing with which most working engineers must deal.[40]

An important related issue is the extent to which students should be exposed—on campus and off in neighboring industry—to up-to-date engineering equipment and technology in college. Outdated facilities and equipment are a growing problem throughout science and engineering education, in teaching and research, but the problem is most severe in engineering.+*

[35] Carolyn M. Jagacinski et al., "Factors Influencing the Choice of an Engineering Career," *IEEE Transactions on Education*, vol. 28-E, No. 1, February 1985, pp. 36-42.

[36] Engineering Manpower Commission, *Engineering and Technology Degrees* (Washington, DC: American Association of Engineering Societies, published annually). Unless otherwise noted, engineering degree data are from the Engineering Manpower Commission. The Commission data at all degree levels tend to be slightly higher than data reported by the National Research Council and the U.S. Department of Education's Center for Education Statistics, but follow a similar pattern.

[37] Ibid.; U.S. Department of Education, op. cit., footnote 1, p. 184. In addition, at least 20 percent of master's-level engineers are employed in the defense industry (National Science Foundation, unpublished data).

[38] Elinor Barber and Robert Morgan, "The Impact of Foreign Graduate Students on Engineering Education," *Science*, vol. 236, No. 4797, Apr. 3, 1987, pp. 33-37; National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook*, NSF 86-305 revised (Washington, DC: 1987).

[39] National Research Council, *Survey of Earned Doctorates* (Washington, DC: published annually). Ph.D. s in engineering research are discussed along with the Ph.D. science work force in the section that follows on "Graduate Education."

[40] These observations on tensions and trends are based on Steven L. Goldman, "A History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, September 1987. Also see National Research Council, *Engineering Education and Practice in the United States: Engineering Infrastructure Diagraming and Modeling* (Washington, DC: National Academy Press, 1986); National Academy of Engineering, *Engineering Undergraduate Education* (Washington, DC: National Academy Press, 1986).

[41] Independent surveys—by the National Science Foundation, the National Society of Professional Engineers, and OTA–of heads of engineering departments at major universities all support this conclusion. See *Chemical and Engineering News*, "Engineering Equipment Needed," vol. 66, No. 1, Jan. 4, 1988, p. 19. The National Science Foundation

Photo credit' University of Tulsa and The Chronicle of Higher Education

The majority of engineers work in industry, and universities are expected to train engineering students using equipment similar to that *which they will use in industry. Here,* a student at the University of Tulsa, Oklahoma, inspects an oil well drill bit that is part of the university's full-scale research drill rig. Much university engineering equipment is outdated, and replacements are increasingly expensive.

Computers for design, sophisticated production machinery, and other equipment have revolutionized practice in many fields of engineering, and universities must teach their students about current technology. It is increasingly difficult for engineering schools to finance the continual upgrades in equipment and facilities required for high-quality engineering teaching. This problem is especially severe in the 200 comprehensive schools (those below the top 50 or so, as measured by the number of engineering degrees awarded), which produce about half the B.S. engineers.

There are a variety of ways to expose students to new engineering technology and the work conditions of real engineers, without attempting to match industrial facilities. Some of the technology (for example, that of computer-aided design) can be simulated by computers. Cooperative work-study arrangements with industry, part-time employment, and summer internships are also helpful.[42] These programs give students the first-hand experience of actual engineering practice. The use of adjunct faculty borrowed from industry is another way to impart up-to-date knowledge of industrial methods.

The Transition to Work

Employers customarily train young engineers, normally hired with only bachelor's degrees, to meet the particular demands of their firms. This on-the-job training socializes engineers and overcomes what many in industry see as an overly theoretical bias imparted by engineering schools. Employers, by and large, do not expect new B.S. engineers to be fully competent for 6 to 12 months after hiring.

Employers are finding that the speed of change in engineering technology recently has left engineering schools further and further behind in exposing students to current techniques and working conditions. This development places a growing training burden on industry, and both universities and companies are adjusting their methods accordingly. Part-time jobs, internships, and cooperative work-study programs in industry are all regarded as excellent opportunities to orient students to the working conditions, culture, and technology of actual engineers.

report *observes that, "Engineering may be a field that has been running hard just to stay even and that soon may have increasing difficulties in maintaining current stocks of basic research equipment. " National Science Foundation, Academic Research Equipment in the Physical and Computer Sciences and Engineering: 198.? and 1985—Executive Summary*, SRS 87-D6 *(Washington, DC: October* 1987), p. 9.

[42]Cooperative education—student work in industrial or corporate *settings—is particularly important for providing role models and* career guidance. *Engineering cooperative graduates, like other cooperative students, tend to receive higher salaries and better jobs after graduation, yet they are no less likely than other engineers to enter graduate school. See Richard P. Nielsen et al., An Employer's Guide to Cooperative Education (Boston, MA:* National Commission *on Cooperative Education,* 1987).

Industry, which has a long tradition of on-the-job training for young baccalaureate engineers, has in these ways expanded its influence on the engineering schools in recent years. The Federal Government, by promoting joint industry-university R&D programs and by establishing federally funded engineering centers on campuses, is encouraging this more expansive role.[41]

Another continuing tension is over the length of the engineering curriculum. For decades, the expanding technical content of many engineering fields has created pressure to institute 5-year engineering programs in place of the traditional 4-year course. A few institutions have done so, but more have abandoned this experiment. One issue is whether this additional coursework should consist of technical electives or "liberal studies." The point may be moot; industry enthusiasm for these programs is lukewarm, since on-the-job training of young engineers can more easily be tailored to firms' particular needs.

Engineering Attracts Few Women and Minorities

The places of women and minorities in engineering education, as in the engineering work force, show continuing inequities (see table 3-2). The proportion of women in engineering undergraduate programs, after 15 years of steady gains, during which they rose from 1 to 15 percent of the bachelor's degrees awarded annually, leveled off in 1985 and dropped in 1986.[44] Freshman women's degree intentions indicate that they will not continue their progress toward equal representation in the near future; interest is actually slumping. Women represent only 3 percent of the engineering work force. They concentrate in chemical and industrial engineering, and are less well represented in high-growth fields such as electrical engineering.[45]

Blacks and Hispanics, too, earn a small fraction of the degrees awarded in engineering. Blacks, in 1986, received less than 3 percent of the engineering baccalaureates, a similar share as in 1979. Hispanics, with about 7 percent of the U.S. population, received about 2.4 percent of the engineering baccalaureates. These modest levels of participation by both groups are exacerbated by high attrition; about half of the Hispanics and one-third of the Blacks who enroll in engineering as freshmen complete their undergraduate degrees. (The national average is 30 to 40 percent. Also, few opportunities are given to late entrants, owing to the sequential nature of the required preparation.) Intervention programs, such as the Minority Engineering Program now operating throughout the California State University system, have increased student persistence to the baccalaureate.[46]

Table 3-2.—Engineering Degrees, by Level, Sex, and Race/Ethnicity, 1986

	Percent of degrees		
	B.S.	M.S.	Ph.D.
Women	14.3	11.9	6.7
Black	2.7	1.5	0.5
Hispanic [a]	2.8	1.4	1.0
Asian/Pacific	6.2	7.4	6.2
American Indian	0.2	0.1	–
All minorities	11.9	10.5	7.8

[a]Includes degrees awarded at the University of Puerto Rico. Excluding this university drops the Hispanic B.S. rate to 2.4 percent.

SOURCE: Engineering Manpower Commission, 1987.

Foreign Citizens in Graduate Engineering Education

The most fundamental recent development in graduate engineering education is the large foreign influence in U.S. engineering schools. Engineering and some fields of science, such as mathematics and physics, have long had significant numbers of foreign-born faculty, most of whom have become naturalized citizens. The influx of foreign students during the last decade, though, is of an unprecedented scale. More than half the engineering students in American graduate programs today are foreign citizens, most of whom hold temporary visas

[41]Nam P. Suh, "The ERCs: What We Have Learned," *Engineering Education*, vol. 78, No. 1, October 1987, pp. 16-18; Don E. Kash, *The Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987); Debra M. Amidon Rogers, "Meeting the Global Challenges of a New Era," *Engineering Education*, vol. 78, No. 4, January 1988, pp. 222-223.

[44]Vetter, "Women's Progress," op. cit., footnote 14, pp. 4-5.

[45]Office of Technology Assessment, op. cit., footnote 6, pp. 69-79.

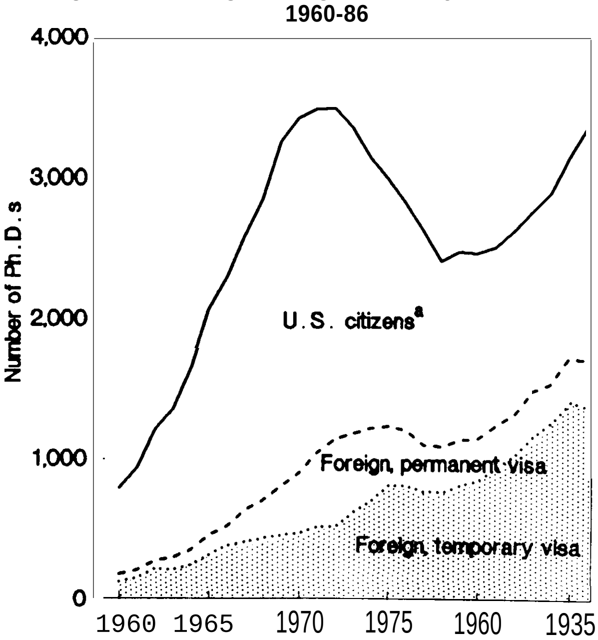
[46]For a review of national minority engineering programs, including the institutions most productive of minority engineers, see *Black Issues in Higher Education*, "Special Report: Engineering Education," vol. 4, No. 15, Oct. 15, 1987, pp. 9, 12-15. Also see Edmund W. Gordon et al., *A Report to the Field: A Descriptive Analysis of Programs and Trends in Engineering Education for Ethnic Minority Students* (New York, NY: National Action Council for Minorities in Engineering, 1987).

that call for eventual return to their native lands. Fewer and fewer U.S. citizens are willing to forego the lucrative salaries that new baccalaureate engineers (and some scientists) can obtain, in favor of several years of graduate student poverty that will yield them a few thousand dollars more in annual starting salary. Today, more engineering Ph.D. s are awarded to foreign-born students than U.S. citizens (figure 3-8). University faculties are even more heavily weighted toward non-U. S. citizens, especially at the assistant and associate professor levels.[47] While half of foreign engineering graduate students plan to join the U.S. work force, about 60 percent of foreign students obtaining Ph.D.s in the United States remain here (see box 3-D).[48]

[47] Paul Doigan and Mack Gilkeson, "*Engineering Faculty Demographics: ASEE Faculty and Graduate Student Survey, Part II, Engineering Education,* vol. 77, *January 1987, p. 208.*

[48] National Science Foundation, *National Patterns of Science and Technology Resources (Washington, DC:* **1986),** *p. 25; U.S. General Accounting* Office, *Plans of Foreign Ph.D. Candidates: Plans of U.S. Trained Foreign Students in Science/Engineering, GAO/RCED-86-102FS (Washington, DC: U.S. Government Printing Office, February 1986),* p. 3; National *Research Council, Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues (Washington, DC: National* Academy *Press, 1988), p. 2; National Science Foundation, op. cit., footnote* 38.

Figure 3.8.—Engineering Ph.D.s, by Visa Status, 1960-86



[a] Includes unknown citizenship (currently about 8 percent of total).

SOURCE: National Research Council, *Survey of Doctorate Recipients.*

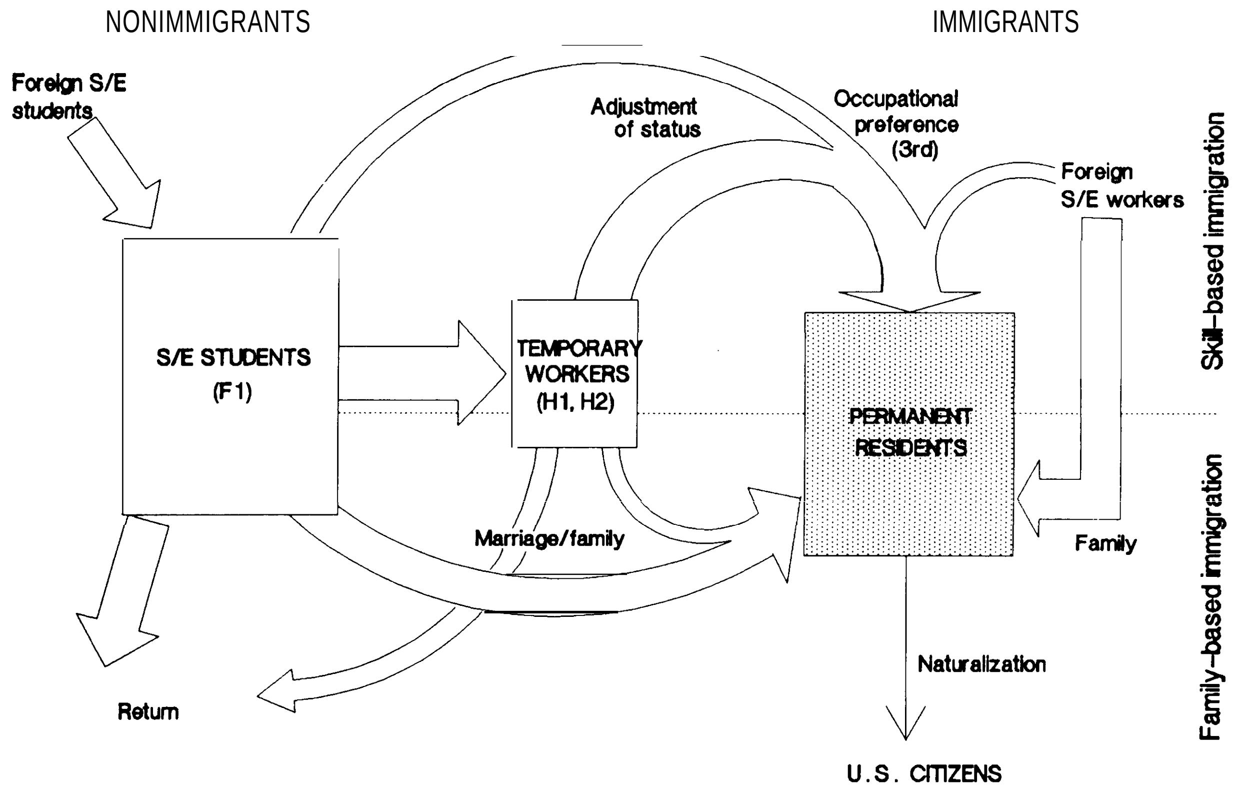
Box 3-D.—Immigration Policy and Practice: How **Foreign Nationals Enter the** U.S. Science and Engineering Work Force

Foreign nationals enter the U.S. science and engineering work force by several paths. Knowledge of the different paths of immigration and the requirements and regulations for each is important for guiding policy on the flow of foreign scientists and engineers into and out of the United States. Immigration is controlled by laws and by rules and regulations set by the Immigration and Naturalization Service (INS), the Department of Labor, and the Department of State.[1] Most immigration policy is set by INS, although the Department of State actually issues all visas. Immigration into the United States falls into two broad categories: immigrants exempt from limits (for immediate family and refugees) and immigrants subject to quotas (that give preference, for example, to distant family members and workers with needed skills).

Temporary Entry—Students and Temporary Workers

Like all immigrants, many immigrant scientists and engineers first enter the United States as temporary workers or students (see table and diagram below). Foreign science and engineering students, visitors, and temporary workers may enter the United States without limitation, and contribute significantly to U.S. research during the years they are here. It is widely believed that about half of foreign science and engineering students stay in the United States for at least a few years after graduation in order to work, and many of these stay for many years or permanently.[2] The university route to immigration has become more important relative to direct immigration into the work force since 1976, when immigration law changes made it difficult for foreign workers to enter without a firm job offer.

Most foreign students enter the United States on F-1 temporary student visas, usually issued for the entire anticipated duration of study. Some enter on J-1 exchange visitor visas, which usually require that the visitor



SOURCE: Office of Technology Assessment, 1988; based on data from the Immigration and Naturalization Service.

or student return to his or her native land before seeking permanent residence in the United States. A small number of foreign students are already permanent residents of the United States on the basis of family ties, and require no further permission to be students. There are no quotas on student visas, and essentially all student visa applications are approved. (Applicants must have been admitted to a U.S. institution and show 1 year of available funds and access to support for the duration of their studies; foreign students may not work, except on campus.) About half of foreign students major in science or engineering.]

When a student graduates, he or she may apply to INS for a l-year extension for "practical training" in their field. Such extensions are almost always granted. During this period foreign students may hold paying jobs. Foreign scientists and engineers may also stay temporarily in the United States under a different visa category, H visas, for temporary workers of distinguished ability (H-1 visa), with needed skills (H-2), or trainees (H-3). Most such temporary workers have already been in the United States as students, and adjust their visa status upon application to INS; others come directly from their home country. There are several subclasses of temporary workers, Most scientists or engineers work under H-1 visas, for temporary workers who are professionals (which includes most science or engineering graduates) or of distinguished merit or ability. To be admitted to H-1 status, an applicant must have a job offer and the prospective employer must demonstrate to the INS that the individual has special skills and that the job that the individual will undertake requires such skills. A few scientists and engineers work under H-2 visas, for which the employer must establish for INS that there are no U.S. citizens willing and able to take the position, and that admission of the individual will not adversely affect labor markets. The individual does not necessarily have to be of extraordinary merit, The H-1 and H-2 visas can normally be renewed annually, under current INS policy up to a maximum of 5 years. There is no limitation on the number of H-1 and H-2 visas that maybe issued annually. It is usually quite easy for a foreign science or engineering student to adjust to temporary worker status.

Immigration

Foreign nationals can work temporarily in the United States under either the F-1 practical extension or the H-1 and H-2 status, but cannot reside permanently in the United States on these visas. There are two routes by which foreign nationals can become permanent residents, a status which allows them to work and live in a manner equivalent to U.S. citizenship. (Achieving permanent residence is the major hurdle for foreign citizens. Permanent residents are for most purposes the same as U.S. citizens; naturalization is merely validation.)

The first route is marriage or being part of the immediate family of a U.S. citizen. In this case, permanent residence is granted for family reunification and entry is granted without reference to the person's skills. There is no limit on the number of people admitted on this basis. Most scientists and engineers who achieve permanent residence do so through this path.

About 30 percent of the scientists and engineers that become permanent residents do so on the basis of occupational preferences, and the number of people admitted on this basis is controlled by annual worldwide quotas set by INS. Scientists and engineers most commonly enter under the third preference, for professionals of particular skills. Some enter under sixth preference for skilled or unskilled workers. For admission under the third or sixth preference, the applicant's employer is required to petition the Department of Labor to show that admission of the applicant would not adversely affect U.S. workers similarly employed and that that there are no U.S. citizens with the skills or the inclination to take the job in question. A very few scientists and engineers of professional reknown and international reputation enter under Schedule A, group II—a select list of occupations for which the Department of Labor (DOL) has already determined that there is a shortage of U.S. citizens. (Although DOL makes the list, INS decides who qualifies for immigration under Schedule A. Engineers used to be, but are no longer, on Schedule A.) Following approval by the Department of Labor ("labor certification"), the applicant then must petition the INS, which considers the application on the basis of geographic and other quotas.

Although immigration policy governs the entry and exit of foreign scientists and engineers, other influences affect the pressure on that immigration system. Federal and university policies on tuition and awarding various forms of support to foreign citizens affect the attractiveness of study at U.S. universities, although most foreign students bring substantial support with them. Federal, State, and corporate employment policies, particularly for defense-related work, shape the job market for foreign nationals. And political and economic conditions in foreign countries drive the flow of their citizens abroad.

The system of temporary and permanent immigration to the United States has evolved gradually over time and has been amended to reflect changing priorities. Among the many goals of immigration policy are promoting tourism and increasing international exchange and understanding; unifying and reunifying families; encouraging talented people to bring their skills to the United States; offering a safe haven to refugees from from war; protecting American workers; and controlling the national origins of immigrants to the United States. Since immigration practices are often built around achieving each goal separately, these goals sometimes conflict.

[1] The Immigration and Nationality Act of 1952, as amended by various laws, particularly the *Immigration and Naturalization Act of* 1965 (which ended national origin quotas, created preference groups, and introduced labor certification), the Eilberg Act of 1976 (which tightened labor certification requirements), and the Immigration Reform and Control *Act of* 1986. The lead Federal agencies have considerable discretion in setting policy. The immigration system is large, complex, and fairly individualistic; there are always minor exceptions to general practice.

[2] Michael G. Finn, Oak Ridge Associated Universities, *Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982*, (Oak Ridge, TN: June 1985), cited in National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook*, NSF 86-305 revised (Washington, DC: 1986), p. 39.

[3] Institute for International Education, *Open Doors 1985/86* (New York, NY: 1986).

The high quality of foreign-born students and faculty is not at issue. Furthermore, without them, many graduate engineering programs would have to close their doors, and engineering faculty would be scarce. However, worry about language problems and the impact of cultural differences on the future engineering work force are warranted. Some women engineering students, for example, have reported discrimination by foreign faculty and graduate teaching assistants that exceeds the residual sexism they encounter in the predominantly male culture of engineering education.[49]

[49] T.A. Heppenheimer, *"Engineering Education: Stability Under Strain," Mosaic, vol. 18, No. 1, spring 1987, pp. 18-25; National Research Council, op. cit., footnote 48, p. 8.*

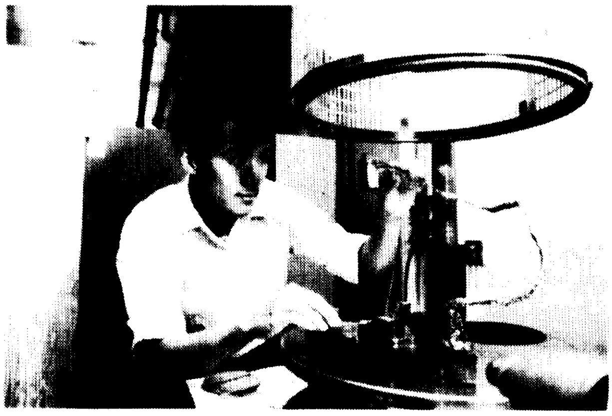


Photo credit: California Institute of Technology

Foreign citizens who attend American universities to study science and engineering are generally regarded as excellent and hardworking, and many stay in the United States and join the work force. However, the high proportion of foreign citizens in some fields, particularly engineering and mathematics (and to a lesser extent computer science, physics, and agriculture), has raised various concerns. Most observers believe that the underlying problem is a paucity of American citizens willing to undertake graduate study in science and engineering. While some favor changing immigration policy to encourage foreign Ph.D.s to stay in the United States, others are calling for limits on Federal funding of foreign citizens in universities. In addition, some academics are concerned about the effect that the influx of foreigners is having on university teaching.

Related to the foreign component of the U.S. engineering work force are the effects of the defense buildup by the Reagan Administration. About one-quarter of all engineers now work on defense projects.[50] Some argue that these projects drain talent from the civilian sector, but others hold that military spending has boosted the supply of engineers. American students' loss of interest in engineering, particularly at the doctoral level, is a concern for the Department of Defense (DoD), since DoD's use of foreign engineers is largely prohibited by Federal security and employment laws. Partly to compensate, DoD is devising programs to bring more women and minorities into the talent pool.[51]

‘{’National Research Council, *The Impact of Defense Spending on Nondefense Engineering Labor Markets* (Washington, DC: National Academy Press, 1986).

[51]For example, see Nina W. Kay, Huston-Tillotson College, Center for the Advancement of Science, Engineering, and Technology, “A Study to Determine and Test Factors Impacting on the Supply of Minority and Women Scientists, Engineers and Technologists for Defense Industries and Installations,” unpublished manuscript, 1987.

Photo credit: MESA Program

Large amounts of Federal R&D funds are spent on defense projects. Some argue that this spending draws disproportionately large numbers of students, particularly the most talented, away from the civilian sector and has detrimental effects on their training. Others argue that defense spending has boosted the supply of scientists and engineers, absorbed labor surpluses, and spurred leading-edge research. In either case, because of prohibitions on the use of foreign nationals in defense work, the Department of Defense is particularly keen to attract more U.S. citizens in the talent pool.

Engineering technicians and technologists form a large potential reserve stock of talent. The Nation's 1 million engineering technicians (compared with about 2.4 million engineers) are an important part of the engineering labor force, and they are a potential source of engineering skills. Some have already received training through specialized 2- and 4-year engineering technician and engineering technology programs, which are increasing nationally.[52]

The Need for Continuing, Life-Long Education

The fast pace of technological change has increased the need for mid-career retraining of engineers. Most agree that this need is not being met. Industry, which traditionally has preferred to hire and train young baccalaureate engineers rather than

[52]The problem is that engineering technology is still searching for an identity and full citizenship in the world of engineering. See Lawrence J. Wolf, “The Emerging Identit, of Engineering Technology,” *Engineering Education*, vol. 77, No. 7-8, April/May 1987, pp. 725-729. A bill, H.R. 2134, was introduced in the 100th Congress proposing a National Advanced Technicians Training Act. It calls for the National Science Foundation to designate 10 centers of excellence among community colleges to serve as clearinghouses and model training programs. See *Congressional Record*, vol. 133, No. 62, Apr. 22, 1987.

retrain its old stock, has not been a leader in continuing education.[51] Some universities, sensing the market opportunities, are reluctantly beginning to provide this training, but it is clear that their priorities remain teaching the young and conducting research. However, there are many engineers with out-of-date skills, and education to update them could be an efficient way to increase both the supply and quality of engineers.

One promising approach to mid-career training is to use computer and information technology to provide training programs at workplaces, rather than at university campuses. The National Technological University, a consortium of 30 universities, offers master's-level engineering courses via satellite video, with two-way audio connections to companies' premises. Preliminary evaluation indicates that learning in this way is highly successful and that cost savings are substantial.[54] Other programs based on this model are beginning to be established, though widespread emulation is by no means assured.

Scope for Federal Policy in Engineering Education

Although industry and universities are the key players in engineering education, the Federal Government has a place and is increasing its policy influence. The international competitiveness of American industrial performance has caused the National Science Foundation (NSF) to pay a great deal more attention to engineering than it did a few years ago. Infrastructure, faculty, and students all need attention, and this intervention is timely. Some efforts to encourage the interplay of engineering theory with industry practice have been mounted in the NSF Engineering Research Centers, and additional steps could be taken by the national laboratories (such as playing host to cooperative education students). Evolving relationships between industry and universities will tend to narrow the gap between engineering as taught in engineering schools and as practiced in the world of employment.[55]

Federal R&D funding affects the supply of engineers indirectly, but substantially, by shaping industrial and academic engineering programs. Other than this influence, the Federal role in alleviating shortages of particular engineering specialties is limited to assisting undergraduate and graduate education, technician training, and continuing education. In the long run, interventions in the elementary and secondary education of students in mathematics and science, where talent is first identified and nurtured, will be necessary.[56]

Most engineering institutions will require not only Federal help in refurbishing their equipment and facilities, but assistance in inducing U.S. students to pursue graduate study. Most schools can neither acquire the costly design and production technology equipment that has swept through industry in the past decade, nor afford to turn away the impressive foreign talent clamoring for admission. Engineering institutions will have to juggle the resources at their disposal and adapt their pedagogical use of technology, both local and remote, to maintain the quality of education they offer.

[51] There are notable *exceptions, such as IBM and Hewlett-Packard. Estimates of the cost of retraining by U.S. industry–all personnel, not just engineers—range* into the *billions of dollars.*

[54] A *task force of the American Society for Engineering Education recently lauded the pioneering efforts of the Association for Media-Based Continuing Education for Engineers (a consortium founded in 1976 with funding from the National Science Foundation and the Sloan Foundation), as well as the National Technological University, for their "integration of learning modules with new communications technologies in order to free continuing education from time and distance constraints." American Society for Engineering Education, A* National *Action Agenda for Engineering Education (Washington,* DC: *1987),* p. 28.

[55] An example *is* the *Semiconductor Research Corp. formed* in 1982 *to facilitate technology;' transfer among U.S. industry, government, and institutions of higher learning. See Ralph K.* Cavin, *111 and D. Howard Phillips,* "SRC: *A Model of Industry-University Cooperation," Engineering Education, vol. 78, No. 4, January 1988, pp. 224-227.*

[56] The *National Action Council for Minorities in Engineering, the Southeastern Consortium for Minorities in Engineering, and the Junior Engineering Technology Society all sponsor programs dedicated to augmenting school experiences and creating interest in engineering as a career. See, for example, National Action Council for Minorities in Engineering, Long Range* Plan *1986-1995 (New York, NY: December 1986).*

GRADUATE EDUCATION: ENTERING THE RESEARCH WORK FORCE

Key Questions

- How healthy is graduate education? How are research universities responding to the cooler climate for academic research and an increased emphasis on exploitable areas of science than prevailed two decades ago?
- How important is Federal funding of graduate education? Are some support mechanisms more effective than others in expediting completion of the Ph. D.?
- What factors seem to attract students, particularly women and minorities, to graduate study in science and eventual degree-taking?

Key Findings

- The quality of most Ph.D.-granting science programs and their graduates is very high. The university-based research apprenticeship is a strength of the U.S. system, and in many fields sets a global standard.
- Graduate education in the sciences is a long (an average of 7 to 8 years after the baccalaureate) and expensive process; a variety of support mechanisms (teaching assistantships, research assistantships, and fellowships) sustain students en route to receipt of the Ph.D.
- Federal funding has a direct positive effect on Ph.D. production. Fellowships and traineeships in particular have been a straightforward way to increase Ph.D. production in science and engineering.
- The size of the debt incurred during undergraduate education may deter minority students from electing graduate study.
- In retrospect, infusion of Federal R&D funds to science and engineering graduate programs in the 1960s was a principal cause of the rapid expansion of American graduate schools. As the number of scientists and engineers has grown, so has the competition for research grants and the need for equipment and faculty. This expansion has taxed the system of university basic research and graduate training, and decreased the attractiveness of academic careers.

Acculturation to the Research Environment

Beyond the baccalaureate degree, the educational system offers students two further goals: the master's and the doctoral degrees. For scientists, the doctorate is a research degree, and all hopes are set on it. Master's degrees in science are awarded as specialized stepping stones to doctorates; sometimes they facilitate field-switching, but often they are seen merely as consolation prizes.[57] Master's degrees normally involve some research, but the Ph.D. certifies the ability to do independent research.

For those who enter them, doctoral programs in science signify not only the final step of formal education, but also the initiation into research communities.[58] A nation concerned about the research base of scientists must be deeply concerned about what is happening at graduate schools, for that is where the research base is formed and renewed.

[57] Judith S. Glazer, *The Master's Degree: Tradition, Diversity, Innovation*, ASHE-ERIC Higher Education Report No. 6 (Washington, DC: Association for the Study of Higher Education, 1986).

[58] Alan L. Porter et al., "The Role of the Dissertation in Scientific Careers," *American Scientist*, vol. 70, September-October 1982, pp. 475-481.

Photo credit: University of Chicago

Graduate education in science and engineering involves both advanced study in specialist fields and an acculturation to the practice of scientific research. Students work closely with faculty who become their mentors in what is, in effect, an apprenticeship to research.

Fortunately, American graduate schools are of very high quality. Not only vital to our national competitiveness and quality of life, they are increasingly international resources. In their number, independence, and diversity, and in their historic integration of education with research, they are unparalleled. These same qualities make it difficult to assess their general health and the quality of their outputs, though the increasing numbers of foreign students and faculty entering America's graduate schools are taken by many as a testimony to their strength.

The intertwining of education and research may be the source of this strength; the graduate student is not only a student and scientist in training, but an apprentice researcher as well. Universities are entrusted with the responsibility for most basic research in the United States. Graduate students, especially at the doctoral level, therefore receive important experience in research at the highest professional level.

The Nation's university research enterprise, however, is in transition. After extraordinary growth in the 1950s and 1960s, Federal research funding entered a period of slower growth and decline in the 1970s and 1980s.[59] Graduate enrollments have paralleled funding trends, reflecting also the decline in faculty employment opportunities. Universities have responded by engaging in novel funding and management arrangements with industry and government to maintain their financial and academic health.[60]

[59] Don I. Phillips and Benjamin S.P. Shen (eds.), *Research in the Age of the Steady-State University*, American Association for the Advancement of Science Selected Symposium 60 (Boulder, CO: Westview Press, 1982).

[60] For an overview, see White House Science Council, *Panel on the Health of U.S. Colleges and Universities* (Washington, DC: Office of Science and Technology Policy, 1986). The most celebrated contemporary cases of university accommodation to financial pressures concern partnerships with industry over biotechnology and with the Department of Defense over Strategic Defense Initiative research. See, for example, Dorothy Nelkin and Richard Nelson, "Commentary: University-Industry Alliances," *Science, Technology, & Human Values*, vol. 12, No. 1, winter 1987, pp. 65-74. Universities' most politicized responses to funding pressures have perhaps best been expressed in the competition over siting of the Superconducting Super Collider, and debate over peer review and the growth in congressional earmarking for building construction (laboratories, libraries, centers) on university campuses. For a congressional perspective, see Sherwood L. Boehlert, "Money, Science, and the SSC," *Chemical & Engineering News*, vol. 66, No. 1, Jan. 4, 1988, p. 5.

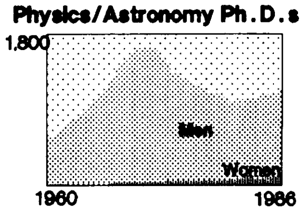
Ph.D. Awards—Toward a Steady State

An OTA analysis of the number of doctorates awarded in each field of science and engineering shows that, during the 1960s, doctorate production underwent a sustained rise that is correlated with increases in Federal funding of research and fellowships. As seen in figure 3-9, graduate enrollments more than doubled between 1958 and 1970, rising from 314,000 to 816,000 as Federal support grew. Since then, slower growth in Federal funding of both R&D and fellowships has been associated with essentially level production of Ph.D.s (figure 3-10).[61]

However, these degree patterns–as depicted by the figures below—have not been uniform. They vary substantially from field to field, and by sex. Also notable is the new role in American graduate programs of foreign citizens. The following are some broad trends:

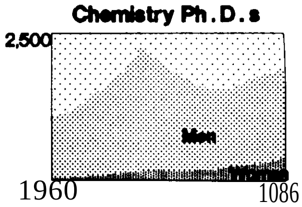
- Graduate physics enrollments are rising, but the increase is due solely to foreign citizens (who constitute one-third). Most physics Ph.D.s go on to postdoctoral appointments and stay in universities. Women earn only about 7 percent of physics doctorates; foreign nationals earn over three times as many.

Physics/Astronomy Ph.D.s



- There is an active industrial market for chemistry Ph.D.s, and chemists are relatively mobile (with as many as one-third of their number employed in other fields). About 25 percent of chemistry Ph.D.s are awarded to foreign nationals, and 20 percent to women,

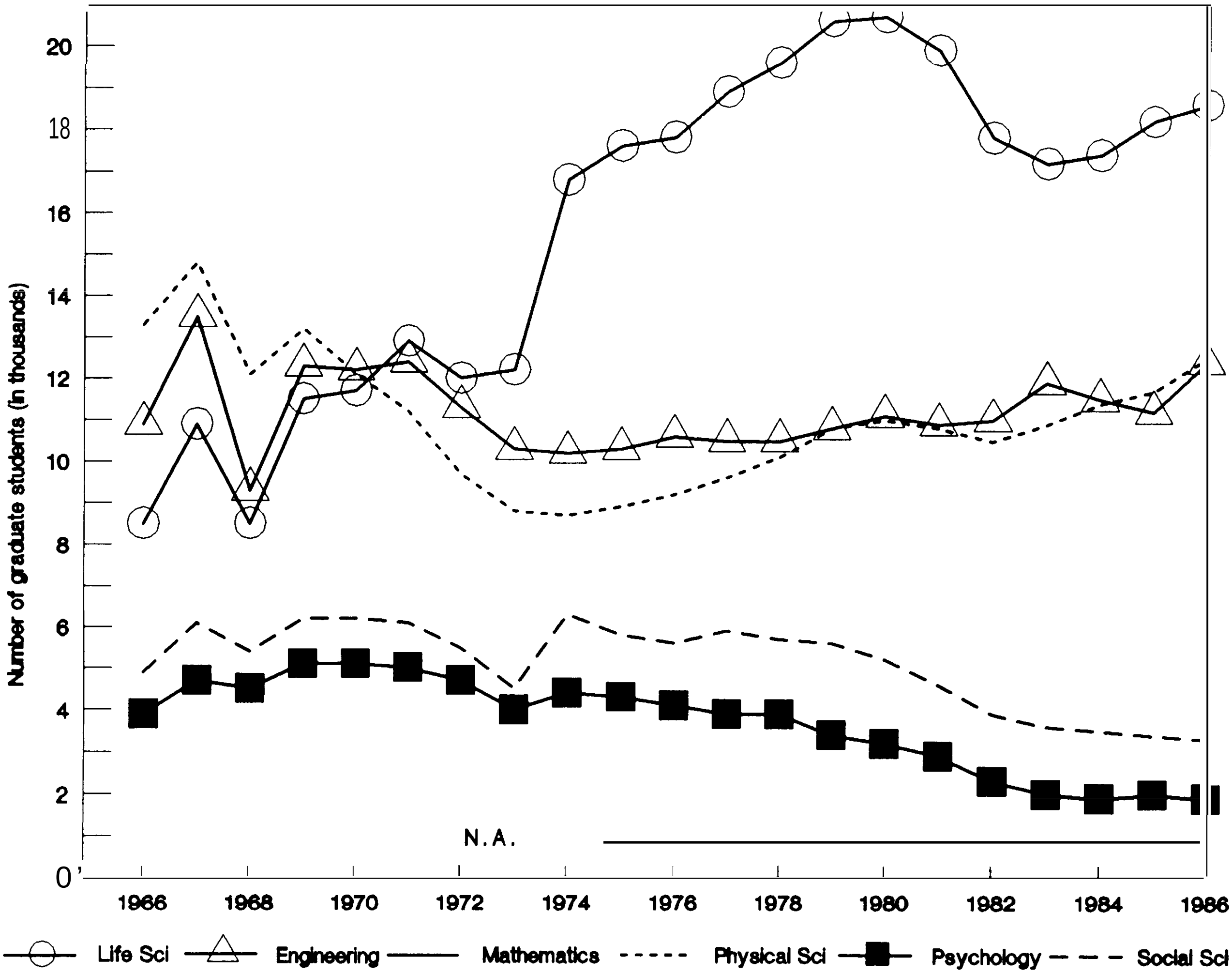
Chemistry Ph.D.s



- Ph.D. production in earth and environmental sciences has been stable during the last decade, following a rapid rise in the 1960s, with geo-

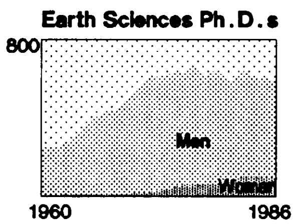
[61] These data and those discussed below are detailed in office of Technology Assessment, op. cit., footnote 6.

Figure 3-9.—Full-Time Science/Engineering Graduate Students With Federal Support in Ph.D.-Granting Institutions, by Field, 1966-86



SOURCE: National Science Foundation, Science Resources Studies, *Academic Science/Engineering: Graduate Enrollment and Support.*

logical science supplying more than half the total. Recent enrollments are down. Women earn 20 percent of Ph.D, s awarded, and 20 percent go to foreign nationals.



- Most Ph.D. mathematicians are employed in universities. Ph.D. awards have dropped by more than half during the last 15 years, and about one-third go to foreign nationals (who, with naturalized citizens and foreign permanent residents, form about 15 percent of the Ph.D. mathematics work force). Forty percent of mathematics baccalaureates are awarded to women, but only 15 percent of the Ph.D. s.

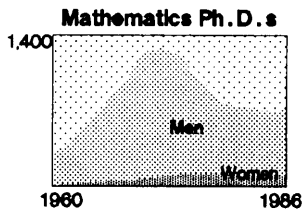
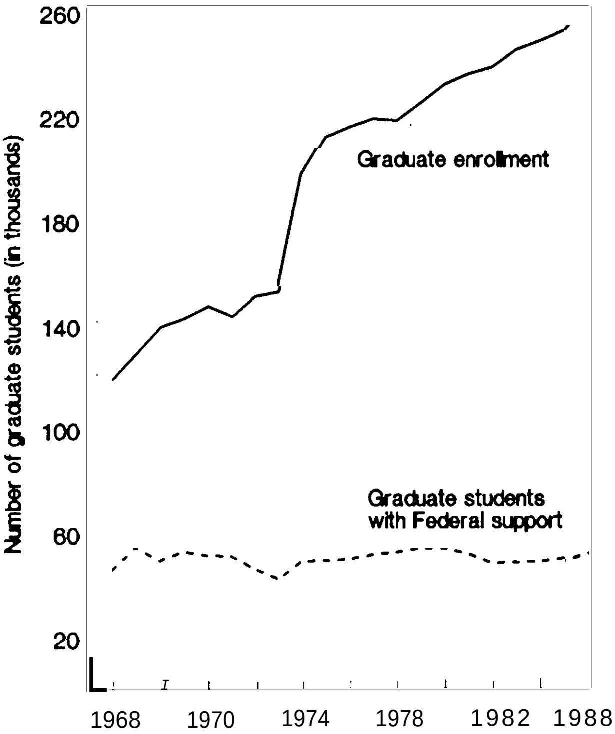
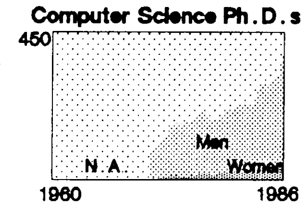


Figure 3-10.– Full-Time Science/Engineering Graduate Students With Federal Support in Ph.D.-Granting Institutions, 1966-86

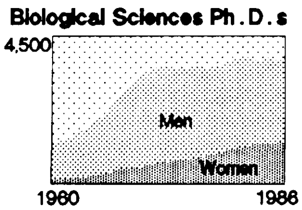


SOURCE: National Science Foundation, Science Resources Studies, *Academic Science/Engineering Graduate Enrollment and Support.*

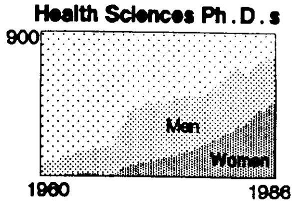
- Computer science has been the fastest growing field of science at all degree levels. Competition for computer science Ph.D.s is keen. Foreign citizens receive one-third of the doctorates (and form one-third of computer science faculties). Women earn 10 percent of the doctorates.



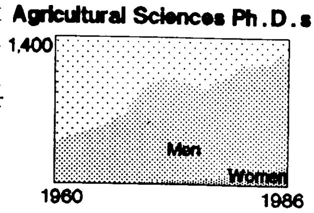
- There is a strong industrial market for doctorates in the biological sciences. Ph.D. production has been stable for the last 10 years, after a decade of increases. Women earn one-third of the Ph.D.s awarded.



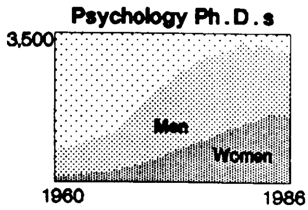
- The number of Ph.D.s awarded in health and medical sciences has increased by 50 percent in the last decade. Most are earned by women; foreign citizens account for about 13 percent.



- Ph.D.s in agricultural sciences have been growing slightly in the last 15 years. Foreign citizens have received about one-third of the Ph.D.s awarded since 1975, but the vast majority return to their native countries.



- Numbers of Ph.D.s in psychology have grown in the last decade, as the numbers of doctorates awarded in other social and behavioral science fields have declined. Enrollments in psychology Ph.D. programs, however, now favor clinical specialties over research and experimental specialties. Women earn more than half of Ph.D.s.



Attrition in graduate school represents a loss of talent to the research work force. As many as half of those who enroll in doctoral programs in science and engineering fail to graduate. Despite the rigorous selection of these students by schools, undergraduate programs, the results of Graduate Record Examinations (GRE), and the availability of financial resources, they are still vulnerable. Reducing their vulnerability would be an easy way to increase the size of the research work force. Increasing the number of fellowships awarded, for example, is a proven method of increasing retention (discussed below). There are large field variations, however, and, since it takes science students an average of 7 to 8 years to receive these degrees, some attrition is inevitable. There is no consensus on what the "natural" rate of attrition should be and how Ph.D.

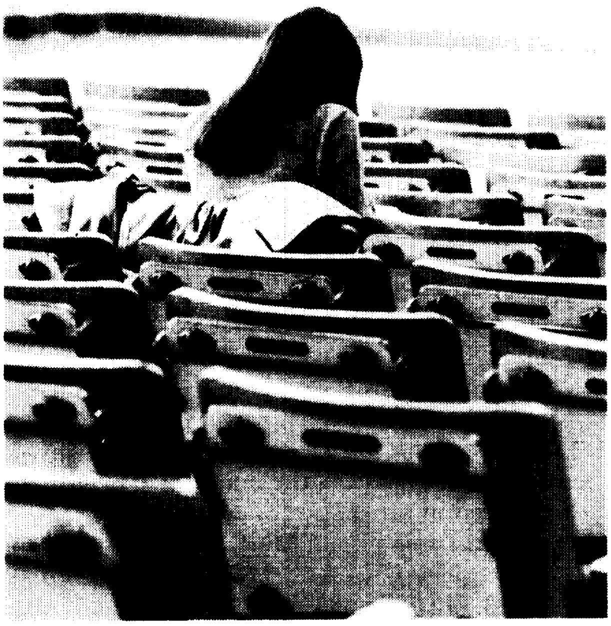


Photo credit: Daniel S. Brody, University of Wisconsin, and The Chronicle of Higher Education

Attrition of graduate students, already a carefully selected and able group, is a serious loss of talent to the research work force; only about half of those who enroll as graduate students in science and engineering eventually graduate with doctorates. Females are especially likely to leave graduate school before graduation. For many students, graduate study is low-paying, lonely, and all-encompassing labor; and few universities have retention programs to help students through these years.

dropouts in particular reflect on the quality of the existing research work force.[62]

The Research Universities

The major research universities educate the majority of the Nation's science and engineering Ph.D.s. These universities number about 100 (out of 330 universities granting Ph.D.s in science). These 100 also win the lion's share of Federal R&D funds; collectively they receive 82 percent of Federal academic science and engineering funds and enroll three-quarters of the full-time graduate students.[63]

Except for a cluster of midwestern (mainly public) institutions, most of the research universities are privately controlled and concentrated on the Atlantic and Pacific coasts. Although their competitive advantage derives from the quality of their basic research, they are often enlisted in Federal research programs aimed at solving social, military, or market problems (such as energy programs in the 1970s), and in industry-funded applied research programs in, for example, materials and microelectronics.

In the 1980s, a changing balance between the competing forces that influence and fund the research universities has challenged graduate education. Despite the Federal Government's vigorous commitment to maintaining basic research funding, the amount of Federal funds offered to the research universities has been declining in real terms, and an increasing fraction has been allocated to military projects.[64] Simultaneously, links with industry have flourished and signs of a reorientation toward applied research are apparent. That reorientation has been encouraged by some States, which have seized on science and technology as drivers of their local economies and devised programs to involve institutions of higher education directly in economic development.[65] Figure 3-11 shows the sources of funding on which U.S. universities and colleges depend. At the same time, many university administrators are finding that science and engineering are victims of their own success; their accomplishments foster the need for ever more costly scientific equipment essential for continued exploration of the natural and human worlds.

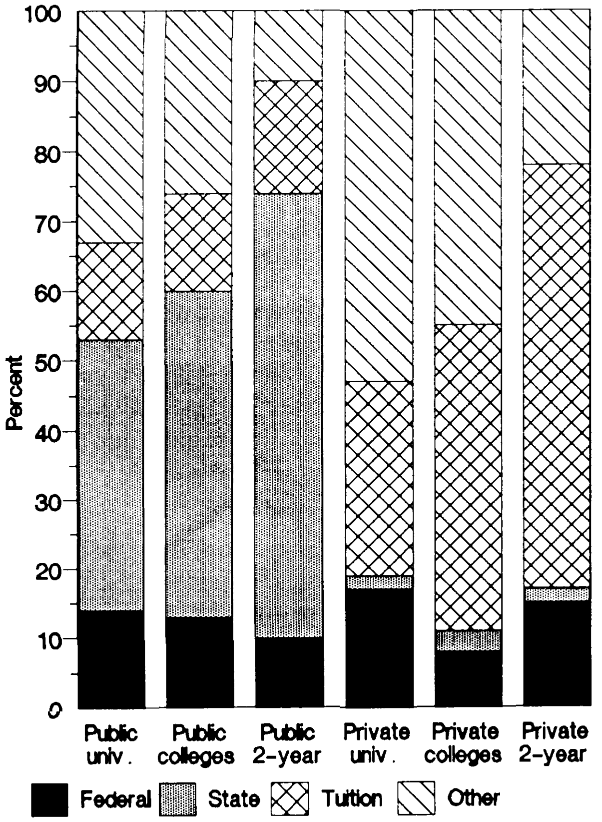
‘Attrition is not a popular topic for study, but see Penelope Jacks et al., "The ABCS of ABDs: A Study of Incomplete Doctorates," *Improving College and University Teaching*, vol. 31, No. 2, spring 1983, pp. 74-81; Ellen M. Benkin, University of California at Los Angeles, "Where Have All the Doctoral Students Gone? A Study of Doctoral Student Attrition at UCLA," unpublished doctoral dissertation, 1984.

[63]U.S. General Accounting Office, *University Research Funding: Patterns of Distribution of Federal Research Funds to Universities*, RCED-87-67BR (Washington, DC: U.S. Government Printing Office, February 1987).

[64]National Science Board, op. cit., footnote 4, ch. 2; Susan L. Sauer (cd.), *R&D in FY 1988: R&D Policies, Budgets, and Economic Competitiveness* (Washington, DC: American Association for the Advancement of Science, 1987), pp. 11-27.

[65]State and regional commissions on science and technology, championed in the late 1970s and early 1980s by North Carolina and New Jersey, are becoming visible resource brokers. Outcomes of these university-industry-government partnerships-jobs, technology transfer, and incentives for further cooperation—remain to be assessed.

Figure 3-11.— Higher Education Revenue Sources, 1986



SOURCE' U.S. Department of Education, Center for Education Statistics, "Financial Statistics of Institutions of Higher Education, " and unpublished data.

Graduate Education in Transition

Students enroll in graduate programs in science for many reasons; foremost among them is interest in research careers. The attractiveness of a research career is strongly influenced by the health of the research universities' research enterprise. That health is not as robust as it could be. Fortified during the 1950s and 1960s by an increasingly rich diet of Federal funds, university research now makes do with a sparser diet of more focused Federal funding. The university basic research and graduate training system can be characterized as in transition to a "steady state" of Federal funding, offset in part by increased industrial funding. For nearly two decades, the research enterprise has been adjusting in this way to a smaller Federal role in R&D support.[66]

Symptoms of this transition are readily apparent. The professoriate is aging. Competition for Federal research funds causes an overemphasis on proposal writing and a dearth of proposal awards, constrained career opportunities for those not on the tenure track, and a consequent growing cadre of soft-monied "academic marginals" and permanent post-doctoral appointees.[67] Still, there is a growing shortage of faculty in some science fields. Retirements are expected to rise; one-third of the professoriate will be replaced in the next 15 years.[68] The current tenure glut that has forced universities to create non-tenure-track positions may be relieved somewhat by these retirements.[69] But universities may not again allow the ranks of permanent faculty to swell, as they did in the golden era of the 1960s, by filling vacated positions with new full-time tenured and tenurable faculty. A dual career ladder may develop in which the traditional professoriate, combining scholarship and teaching, is augmented by new positions giving the academic work force elasticity in

[66] David A. Hamburg, *Carnegie Foundation, testimony before the U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, July 9, 1985, pp. 29-30. A fuller discussion is contained in Phillips and Shen, op. cit., footnote 59, and U.S. Congress, Office of Technology Assessment,* Higher Education for Science and Engineering-A Technical Memorandum, *forthcoming, summer 1988, For a similar perspective on British science, see John Ziman,* Science in a "Steady State": The Research System in Transition *(London: Science Policy Support Group, December 1987).*

[67] Analysis *of this transition is based in part on Edward J. Hackett,* "Science *in the Steady State: The Changing Research University," OTA contractor report, September* 1987. *Also see Harvey Brooks, "What Is the National Agenda for Science, and How Did It Come About?"* American Scientist, *vol. 75, No. 5, September-October 1987, pp. 511-517.*

[68] Irving R. Buchen, *"Faculty for the Future: Universities Have a Rare Opportunity,"* The Futurist, *vol. 21, No. 6, November-December* 1987, p. *22;* H.R. *Bowen and* J.H. Shuster, American Professors: A National Resource Imperiled *(New York, NY: Oxford University Press, 1986).*

[69] The *elimination in 1994 of the Federal mandatory retirement age of 70, however, is unlikely to create a glut of "graying" professors. The age distribution of faculty varies by discipline (computer science faculty are comparatively young, physics faculty old) and spotty data cloud the national picture. Historically, faculty retirements have not been influenced by the mandatory retirement age. Inducements to early retirement, especially benefits offered, are more effective. So planning at the institutional level (and by professional societies—the American Institute of Physics has been studying the issue for over a year) is essential to foresee possible shortages. See Carolyn J. Mooney, "Expected End of Mandatory Retirement in 1990s Unlikely to Cause Glut of Professors, Study Finds,"* The Chronicle of Higher Education, *vol. 34, No. 16, Dec. 16, 1987, pp. Al, 11; Samuel E.* Kellams *and Jay L. Chronister, "Life After Early Retirement: Faculty Activities and Perceptions," Center for the Study of Higher Education, University of Virginia, January 1988.*

response to shifts in Federal and industrial research priorities.[70]

The increasing emphasis on industrial and applied research is also apparent in the rise of research centers, as a complement to project-based funding, and emphasis on team and interdisciplinary research. New pressures for accountability in scientific research are increasing the paperwork burden on the applicants for and recipients of individual investigator awards in universities, without necessarily leading to any measurably better outcomes.[71] OTA concludes that the attractiveness of an academic research career is considerably reduced from its peak of two decades ago, due largely to the adjustment to steady state conditions. The character of the university research enterprise is changing, with basic research and scholarship giving way in part to more industrially focused research and a more directed Federal role.[72]

Whether as a cause or consequence of academia's diminished attractiveness, increasing numbers of new Ph.D.s in science are entering industry. This change in the market for Ph.D.s is reflected in the content and orientation of students' graduate school experiences, which are becoming more industry-oriented in some fields.[73]

The proportion of U.S. citizens with natural science baccalaureates who earn Ph.D.s—never very large–has declined in recent years. The ratio of U.S. Ph.D.s produced in 1975 to baccalaureates produced in 1965 was 1 to 10; it is anticipated that about 5 percent of the recipients of baccalaureate degrees in science in 1984 will ultimately earn a science or engineering Ph.D.[74] Popular explanations for American citizens not pursuing doctoral studies are the time it takes to earn the doctorate, the reduction in stipend support and its replacement with less attractive loans, and a poor labor market for Ph.D.s, particularly in universities.[75] There is little immediate prospect for change in these conditions. If these conditions do not change, enrollments of foreign citizens are likely to increase (if graduate schools maintain their current size and range of research programs),

Foreign citizens are increasingly important to American graduate schools. They are indispensable in some fields of science, as both students and faculty. They fill graduate student places that U.S. citizens are reluctant to fill, they teach undergraduates as teaching assistants, and they keep university research alive as research assistants. While foreign students are required by the Immigration and Naturalization Service to demonstrate that they will be funded for at least 1 year of study, once enrolled in graduate schools they can seek and be awarded many fellowships and assistantships in the same way as citizens. Thus, a significant proportion of Federal funds for science and engineering research at universities is used to educate foreign along with U.S. citizens. Some argue that this funding should be halted, but most believe that the United States gains in the long run from this flow of talent into the country.[76] Many of these students stay, acquire permanent visas, and contribute to the scientific vi-

[70] These "academic marginals" are *typically appointed to "unfaculty" posts affiliated with research centers and institutes on campus. This is elaborated in* Office *of Technology Assessment, op. cit., footnote 66, but see Albert H. Teich, "Research Centers and Non-Faculty Researchers: A New Academic Role, " in Phillips and Shen* (eds.*), op. cit., footnote 59, pp. 91-108.*

[71] For *example, see Deborah* Shapley *and* Rustum *Roy,* Lost at the *Frontier: U.S. Science and Technology Policy* Adrift *(Philadelphia,* PA: *1S1 Press, 1985), chs. 4 and* 6.

[72] "In *the 1980s, Congress has repeatedly signaled its support for restructuring the research system and breaking down the old barriers. The National Cooperative Research and Development Act of 1984 was designed to facilitate joint research among firms in an industry, by offering certain immunities to antitrust actions against such efforts under appropriate conditions. Congress has enthusiastically supported the National Science Foundation's Engineering Research Centers,* Industry*/University Cooperative Research Centers, and Presidential Young Investigator programs, each of which is intended to stimulate cooperative research between universities and industry. Similarly, the Stevenson-Wydler Technology Innovation Act of 1980, and its amendments, the Federal Technology Transfer Act of 1986—along with several recent changes to the patent law—have been designed to stimulate cooperative industrial research . . . ." Christopher T. Hill, "A New Era for Strategic Alliances: A Congressional Perspective," Engineering Education, vol. 78, No. 4, January 1988, pp. 220-221.*

[73] Michael *J. Cluck, "Industrial Support of University Training and Research: Implications for Scientific Training in the 'Steady State',"* OTA *contractor report, August 1987; also see David Blumenthal et al., "Industry Support of University Research in Biotechnology: An Industry Perspective," Science, vol. 231, June 13, 1986, pp. 1361-1366.*

[74] National *Science Foundation, The Science and Engineering Pipeline,* PRA *Report 87-2 (Washington, DC: April 1987), p. 4.*

[75] At least one *commentator attributes the indifference of* U.S. *undergraduate students in science and engineering to undertake graduate study to being "uninformed and misinformed about this option. " His solution, based on meetings with participants in a National Aeronautics and Space Administration summer internship program, is "communication between individual and faculty members and their students. " See Francis J. Montegani, "Why U.S. Science and Engineering Students Pass Up Graduate School-A Different View," Engineering Education, vol. 78, No. 4, January 1988, p. 257.*

[76] For *a discussion of the economic benefits to U.S. society from foreign students, see Donald R.* Winkler, *"The Costs and Benefits of Foreign Students in United States Higher Education, "* Journal of Public *Policy, vol. 4, No. 2, 1984, pp. 115-138.*

tality of the Nation. The rest return home with skills, knowledge, and increased cultural awareness. Providing graduate education to foreign students is becoming a major export activity of the United States, with tuition and board payments from abroad estimated by some at $2 billion annually in all disciplines, about the size of the NSF budget.[77]

[77]Elinor G. Barber (cd.), *Foreign Student Flows*, Research Report No. 7 (New York, NY: Institute for International Education, 1985).

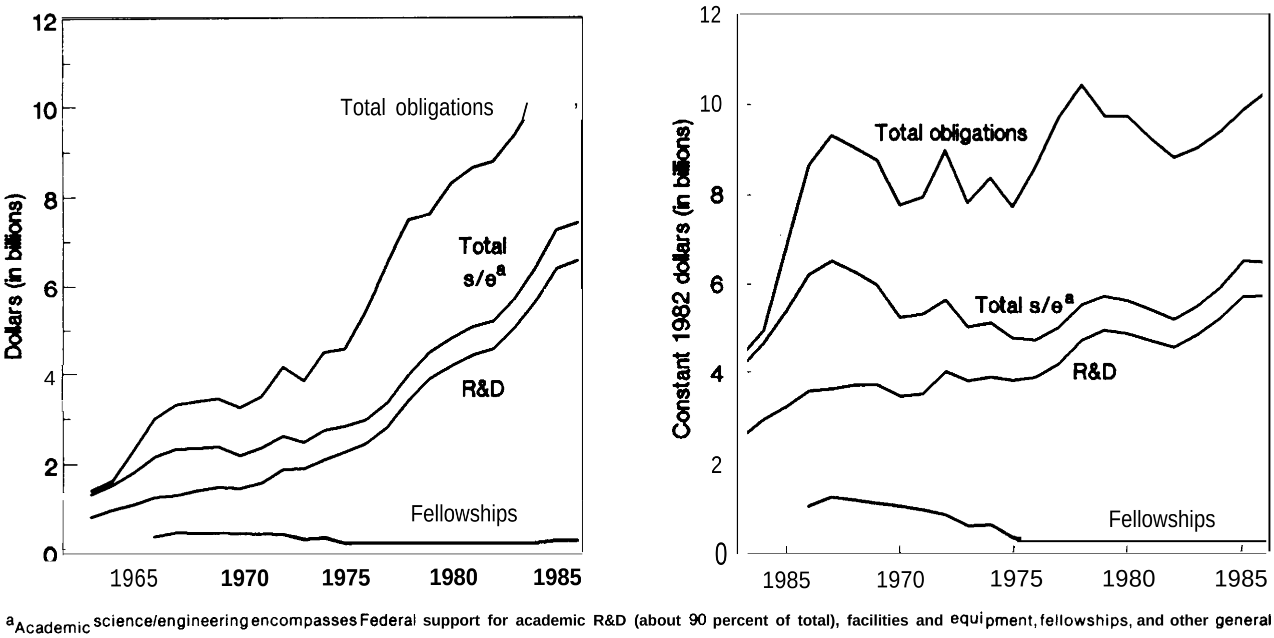
FUNDING OF STUDENTS AND INSTITUTIONS: A TOOL OF FEDERAL POLICY

The Federal Government has a variety of influences, both direct and indirect, on science and engineering education at the undergraduate and graduate levels. Among the direct influences, some, such as basic research spending in universities, are specific to science and engineering. Others, such as support of students and institutions through student loans, infrastructure grants, and other exercises of general Federal stewardship over education and research, have broader application (see figure 3-12).

Indirect influences include tax policies, which affect the nonprofit status of private institutions of higher education and the tax treatment of personal expenditures on education; the military draft and the G.I. bill; laws that prohibit discrimination, such as Title VI of the Civil Rights Act of 1964 and Title IX of the Education Amendments of 1972; and economic policies.

A vital source of indirect Federal influence is the mounting of R&D programs, which can boost the output of scientists and engineers by providing research jobs in government, industry, and academic institutions. (In academic institutions, they also provide student support in the form of research assistantships.) Programs that are large and sustained attract people into undergraduate and graduate studies in relevant fields, thus also creating demand for faculty. Often, such programs are accompanied

Figure 3-12.— Federal Obligations to Universities and Colleges by Type of Activity, 1963.86



[a]Academic science/engineering encompasses Federal support for academic R&D (about 90 percent of total), facilities and equipment, fellowships, and other general science/engineering activities Total academic obligations include, in addition to academic science/engineering, direct Federal obligations for research, facilities, and institutional support not related to science/engineering. Total obligations do not include loans, student support, or other indirect Federal support.

SOURCE" National Science Foundation, Science Resources Studies, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*

Photo credit: National Instltutes of Health

Major Federal R&D programs, such as the War on Cancer in the 1970s, have had the indirect effect of increasing the number of research scientists and engineers. These programs work in two ways: they fund research assistantships in graduate school and increase the attractiveness of scientific research as a career option.

by fellowships and other assistance intended to encourage students to enter relevant fields. The National Defense Education Act of 1958 (spurred by Sputnik), the Apollo Program of the 1960s, and the War on Cancer launched in 1971 provide ample evidence of the Federal power to mobilize research talent.[78]

Federal influence varies greatly by field. In scientific fields that involve mainly academic or basic research, the career outlook for students depends heavily on Federal research programs that dominate universities' research agendas and those of many industries.

Thus, Federal R&D programs affect graduate science and engineering education in four major ways. First, by setting the national research agenda and establishing the demand for science and engineering, they influence students' choices of fields and careers in response to the job markets. Second, Federal funds for the infrastructure of research and education, including institutions, facilities, equipment, faculty, and technicians, maintain the environment for instruction. Third, Federal research grants and contracts support science and engineering graduate students (and a few undergraduates) with research assistantships. Finally, student fellowships and traineeships are awarded on the basis of merit directly to U.S. students by Federal agencies.

Federal programs for undergraduate and graduate education in science and engineering have been mounted by the U.S. Department of Education, NSF, and many other agencies. The scope of these programs and their variety is so vast that it is impossible to evaluate their independent effects or even their overall objectives. Two patterns can be discerned, however, in recent Federal policies: direct funding of individual students to improve access to undergraduate education, and merit-based support to attract graduate students in science and engineering.

Federal Influence on Undergraduate Education

Since science and engineering baccalaureates have maintained a remarkably constant share of total baccalaureates, it is reasonable to conclude that any Federal program that alters the size of undergraduate enrollments will have a corresponding impact on enrollments in science and engineering majors. This proportional pattern is conspicuous throughout the past 30 years, through enrollment boosts resulting from the G.I. bill and the growing participation of larger numbers of women and minority members. This is perhaps the clearest pattern visible in all of higher education. However, Ph.D. awards show no clear relation to B.S. awards in science and engineering; graduate enrollments respond instead to fellowship funding and employment trends in research.

A detailed analysis of Federal influence on higher education[79] reveals that the scale of R&D spend-

[78] An *analysis of how universities responded to the need for more scientists and engineers to support the National Aeronautics and Space Administration and the aerospace industry during the Apollo era, and the effects of ensuing cutbacks in the* 1970s, *appears in Arnold S. Levine, "The Apollo Program: Science/Engineering Personnel Demand Created by a Federal Research Mission," OTA contractor report, December 1986. Also see W. Henry* Lambright, *Launching NASA Sustaining University Program, Limited Advance Edition (Inter-University Case Program, Inc., 1969); Kenneth E.* Studer *and* Daryl *E. Chubin, The Cancer Mission: Social* Contexts *of Biomedical Research (Beverly Hills, CA: Sage Publications, 1980), esp. ch. 3.*

[79] Vetter *and* Hertzfeld, *op. cit., footnote 3. Also see Lawrence E.* Gladieux *and Gwendolyn L. Lewis, The Federal Government and Higher Education: Traditions, Trends, Stakes, and Issues (Washington, DC: The Washington Office of the College Board, October 1987).*

ing, of which the Federal Government contributes about half, has been a major determinant of the supply of scientists and engineers. OTA concludes that legislation increasing opportunity to pursue higher education has had important positive effects on the production of baccalaureate scientists and engineers.

Except for tax-based funds provided to State colleges and universities, the working assumption made in the American system of higher education is that students and their families should pay for it. Support is available to the economically disadvantaged from the Federal Government and from many educational institutions themselves. The Federal Government also provides student loans, which are important in helping retain students through undergraduate education.[80] For the nontraditional student—older, socially or economically disadvantaged, female, minority, or physically handicapped –loans can make the difference between access to higher degrees and blunted career aspirations, since the opportunity costs of higher education for these students are greater. Blacks are more sensitive to loan burdens than whites; they are also slightly more likely to drop out of the science and engineering talent pool under the influences of mounting debt and alternative job opportunities.[81] Kirschner and Thrift note:

> Often, students must assume debt larger than their families' annual income to pay college expenses. Understandably, some students see debt as an unacceptable risk, limiting their options for education.[82]

Support for undergraduate science students differs little from support for undergraduate students as a whole. Students are more likely to stay in school if they receive substantial grants or scholarships. Those who receive grants totaling more than half of tuition are less likely to drop out than those who receive no grants, Pen grants, or some grants.[83] Loans are growing in importance as a proportion of undergraduate student support. Federally supported loan programs grew dramatically through the 1970s and early 1980s, twice as rapidly as overall Federal student aid.[84]

The National Science Foundation has long been a small source of support for undergraduate science and engineering students. Through the 1960s and early 1970s, NSF spent about $30 million per year ($100 million in 1985 dollars) on undergraduate science education. Funding peaked in 1965 and declined until very recently.[85]

NSF support has been concentrated in 4-year colleges without extensive Federal funding or research facilities, where it is intended to provide undergraduate research opportunities. NSF has always preferred funding a few good students, rather than the mass of science and engineering undergraduates.[86] NSF

[80] Arthur M. Hauptman and Charles J. Andersen, "Background Paper on American Higher Education: Report to the Commission on National Challenges in Higher Education," Dec. 16, 1987, p. 3.

[81] Julia Heath and Howard P. Tuckman, "The Effects of Tuition Level and Financial Aid on the Demand for the Advanced Terminal Degree," *Economics of Education Review*, vol. 6, No. 3, summer 1987, pp. 227-238. Michael T. Nettles, *Financial Aid and Minority Participation in Graduate Education*, Research Report of the Minority Graduate Education Project (Washington, DC: Graduate Record Examinations Board and Educational Testing Service, 1987), pp. 3-5.

[82] Alan H. Kirschner and Julianne Still Thrift, *Access to College: The Impact of Federal Financial Aid Policies at Private Historically Black Colleges* (Washington, DC: United Negro College Fund and National Institute of Independent Colleges and Universities, 1987), p. 29.

[83] Undergraduate science students have about the same average student loan load as other undergraduates. Engineering students carry slightly higher debt loads, probably in anticipation of higher earnings. Science and engineering students tend to receive slightly more campus-based aid than average, owing to their higher than average academic ability rather than to their choice of majors. Applied Systems Inc., op. cit., footnote 20. Also see *Manpower Comments*, June 1987, p. 30.

[84] The College Board, *Trends in Student Aid: 1980 to 1987* (Washington, DC: The Washington Office of the College Board, November 1987). Taken together, all forms of Federal financial aid cover about half the costs incurred by students in private colleges and over 60 percent of the costs for students attending private historically Black colleges. Kirschner and Thrift, op. cit., footnote 82, p. 22.

[85] Laurie Garduque, "A Look at NSF's Educational Research Budget," *Educational Researcher*, June-July 1987, pp. 18-19, 23.

[86] National Science Board, Task Committee on Undergraduate Science and Engineering Education, NSB-86-100, *Undergraduate Science, Mathematics and Engineering Education* (Washington, DC: National Science Foundation, 1986), known as the Neal Report. This report identified three areas of undergraduate science and engineering education needing particular attention: equipping laboratories and making laboratory instruction an important and vibrant part of undergraduate education; upgrading the qualifications of faculty; and improving courses and curricula. The National Science Board estimated that of the $42 million spent on undergraduate education in the United States, about half goes to science and engineering. The Task Committee recommended that the National Science Foundation spend an additional $100 million each year on laboratory instruction, faculty enhancement, curriculum development, research participation, instructional equipment, and minority institutions. These funds could be highly leveraged through matching requirements as well as by 'setting examples' for universities, States, and industry to follow. The Task Committee also recommended that National Science Foundation, mission agency, and other research sponsors find new ways to involve undergraduates and undergraduate faculty in research.

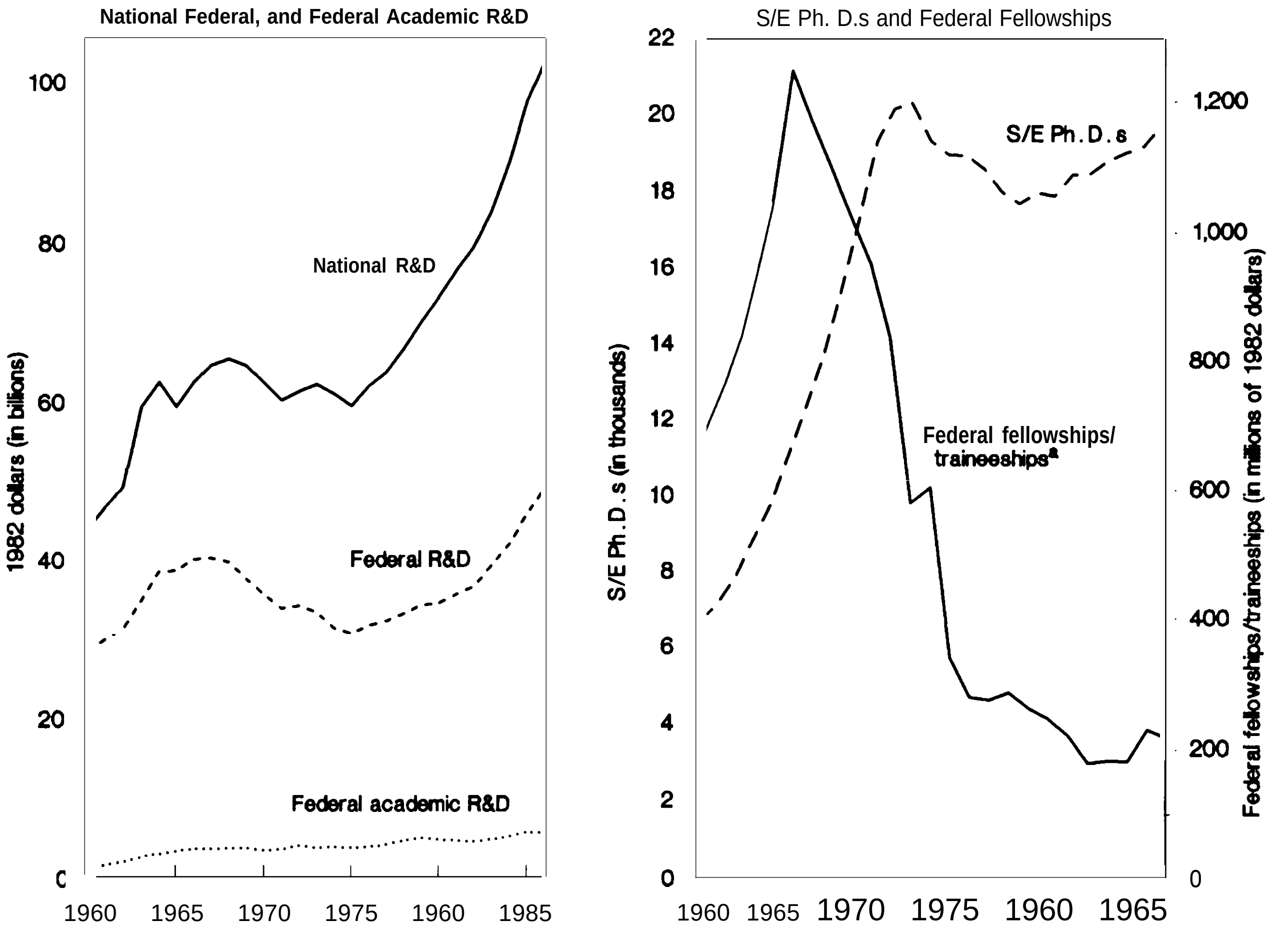
could expand its focus on undergraduate science education through its new Office of Undergraduate Science, Engineering, and Mathematics Education in the Science and Engineering Education Directorate. This office coordinates curriculum development, faculty training, and instructional equipment efforts.[87]

[87]Homer A. *Neal, State University of New York, Stony Brook, testimony before U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Science, Research, and Technology, Feb. 19, 1987, pp. 20-41.*

Support of Doctoral Students: "Buying" Ph.D.s

Federal policy at the undergraduate level has historically been concerned mainly with ensuring access to educational opportunity. At the graduate level, Federal policy focuses on promoting professional training of a small pool of talented students who will form the core of the future research work force. Historical data show that doctoral level science and engineering benefit from the Government's general support for higher education and R&D (see

Figure 3-13.—National and Federal R&D Spending, Science/Engineering Ph.D.s, and Federal Fellowships, 1960-86 (constant 1982 dollars)



[a]Federal fellowships/traineeships from 1960 t. 1964 are OTA estimates, based on Federal fellowship and traineeship data from Federal Interagency Committee on Education, *Report orr Federal Predoctoral Student Support, Part f, 1970,* cited in Robert G. Snyder, OTA contractor report, June 10, 1985, p. 49.

SOURCE: Data on R&D and fellowships from National Science Foundation, Science Resources Studies, *Academic Science/Engineering* and *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions.* Ph.D. data from Betty M. Vetter and Henry Hertzfeld, OTA contractor report, 1987, based on data from U.S. Department of Education, Center for Education Statistics.

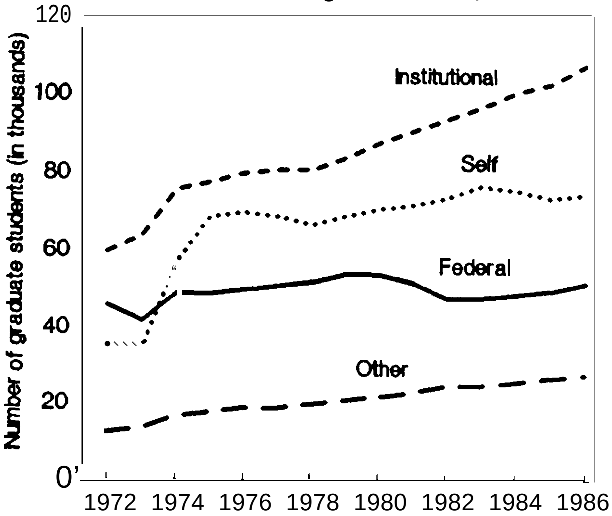
figure 3-13).[88] In each discipline, the attractiveness of a doctoral program in science and engineering has been strongly influenced both by the availability of fellowship and assistantship funding and by the overall outlook for research funding, which shapes the attractiveness of a career in research. OTA also found that the size of the debt incurred during undergraduate education does not affect majority students' graduate study decisions, but may act as a deterrent for prospective minority students.[89]

Up to the graduate level, Federal support of students and universities has diffuse impacts, since most is awarded without regard to academic field. Federal support of science and engineering graduate students, however, has increased since World War II, with periods of rapid expansion, slow growth, and decline.[90] Between World War and the Sputnik-Apollo era, the Federal Government played a minor role in direct support of graduate students; in 1954, only 10 percent of science and engineering graduate students received Federal assistance. After passage of the National Defense Education Act, Federal support boomed. It peaked in 1967 when 42 percent of these students received some form of direct Federal assistance (49 percent in the natural sciences, 32 percent in the social sciences, and 45 percent in engineering). Through the late 1970s into the 1980s, the number of students federally supported declined, while support from other sources grew (see figure 3-14). In 1985, the Federal Government was the major source of support for 20 percent of full-time science and engineering students (26 percent in the natural sciences, 8 percent in the social sciences, and 20 percent in engineering).[91]

The pattern of Federal support continues to shift, with the number of fellowships and traineeships declining and research assistantships (RAs) and loans growing in importance. The system is bolstered strongly by institutional support and State funding, mostly funneled through public institutions. Institutions and States support about 41 percent of graduate students, largely through teaching assistantships (TAs). Self-support has grown since the early 1970s; in 1985 about 30 percent of full-time students relied solely on their own funds. The attractiveness of doctoral studies varies with perceptions of affordability and of available support; once in graduate school, women and minorities are more likely to be self-supported.[92]

Federal fellowships are awarded to the "best" students, as defined by undergraduate accomplishments and GRE test scores, regardless of the institutions they attend. However, these students (about 16 percent of all graduate students) concentrate in the major research universities. Fellowship recipients earn their degrees faster and are more likely to join the science and engineering work force than those with-

Figure 3-14.—Major Sources of Support, Science/Engineering Graduate Students in Ph.D.-Granting Institutions, 1972.86



SOURCE: National Science Foundation, Science Resources Studies, *Academic Science/Engineering: Graduate Enrollment and Support.*

[88] Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need to Know* (Washington, DC: Association of American Universities, 1986).

[89] Janet S. Hansen, *Student Loans: Are They Overburdening A Generation?* (Washington, DC: The Washington Office of The College Board, December 1986).

[90] Vetter and Hertzfeld, op. cit., footnote 3.

[91] Over one-third of science and engineering graduate students attend part time. They are more likely to be pursuing a master's degree and far less likely to receive Federal aid (except loans). See National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1985* (Washington, DC: 1987). Data refer to full-time graduate students in doctorate-granting institutions. Federal support is concentrated in this core population.

[92] Hansen, op. cit., footnote 89. Women, for example, are more likely than men to support themselves as graduate students. This is due only in part to women's choice of fields, such as social sciences, where less external support is available.

out such support.[93] Women fare worse than men or foreign students on temporary visas when it comes to obtaining fellowships; this pattern is believed to be an important factor in the attrition of women in graduate school[94] Federal fellowships, awarded to those identified as prepared for and committed to research careers, have been an effective way of "buying" new Ph.D.s.

Federal research assistantships are tied to faculty grants. RAs support more than 20 percent of graduate students, providing valuable apprenticeship experiences. Recent Federal policy has shifted away from fellowships toward RAs. This shift may have inadvertently increased the accessibility of graduate study to foreign students, who are generally barred from receiving Federal fellowships. TAs (held by about 20 percent of graduate students) also support students in exchange for service to institutions. Almost half of graduate students are at least partly self-supporting, generally with loans.

In sum, a variety of Federal programs, not all intended to serve educational purposes, affect the graduate environment, and thus indirectly affect the supply and demand of scientists and engineers. Immigration laws, R&D tax credits, defense procurement, the taxing of student stipends, legislation to upgrade campus research facilities, and programs of curriculum, faculty, and center development, among other factors, can all affect the quantity and quality of the future science and engineering work force.

"National Academy of Sciences, Committee on a Study for National Needs of Biomedical and Behavioral Research Personnel, Personnel Needs and Training for Biomedical and Behavioral Research (Washington, DC: 1981), pp. 7-10,74-76. Prestigious postgraduate and faculty fellowships, such as the National Science Foundation's Presidential Young Investigator awards, continue this tradition of supporting, on a competitive and matching-fund basis, the very best talent.

[94] Vetter *and* Hertzfeld, *op. cit., footnote 3.*