Chapter 4

Engineering Education

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Engineering education reflects a labor market oriented to production and design, and is sensitive to technological change. About 80 percent of all engineers and most engineering Ph.D.s are employed by industry (see figure 4-l). Engineering enrollments strongly reflect the health and research and development (R&D) activity of relevant industries (often linked to Federal R&D priorities). Engineers can enter the professional R&D work force with baccalaureate or master's degrees, earning more than other new college graduates, and almost as much as Ph.D. engineers. Three of every four new engineering baccalaureate recipients go immediately to industry jobs (see figure 4-2),

STUDENTS AND INSTITUTIONS: AGENTS OF SUPPLY AND DEMAND

The demand for engineers is variable and, in the long term, unpredictable. Most adjustment occurs within the existing work force. Rapidly growing industries sometimes boost demand temporarily beyond the ability of work force reserves and academic institutions to produce engineers. However, employers, the work force, and students adapt well to changing markets. The supply of engineers is augmented and buffered by auxiliary supplies that can be drawn on in times of shortages and transition: engineers and scientists in related fields, technicians and technologists, recent retirees, and engineering managers.

Despite this elasticity in supply, spot shortages and surpluses always occur, and shortages may continue over the longer term. Rapid demand growth usually creates transitory shortages, as seen recently in electronics and computer engineering. Likewise, rapid cutbacks create surpluses, as happened in the early-1980s in petroleum and chemical engineering. Continuing shortages in some areas, such as manufacturing and nuclear engineering, may reflect not only strong demand but also continuing lack of student interest and university ability or commitment to training students in those areas. While the shortages of the early-1980s have eased, employers report shortages in computer and aerospace engineering.[1]

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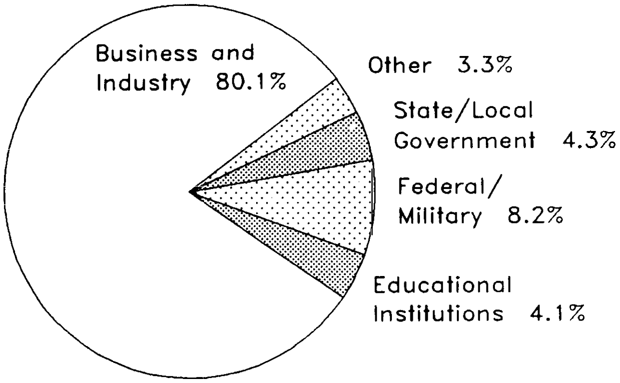
1. According to National Science Foundation surveys of employers and other indicators (the Deutsch, Shea & Evans High Technology Recruitment Index; the Job Offers Index of the College Placement Council; and starting salaries as reported by the College Placement Council, the Recent College Graduate Survey, and the Engineering Manpower Commission). National Science Board, Science *and Engineering Indicators* —

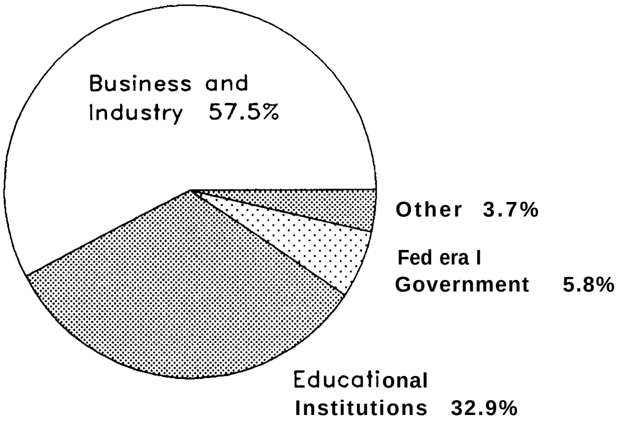
Figure 4-1.-Where Engineers Work, 1985 and 1988

All engineers, 1988



NOTE: n(all engineers) = 2,849,800

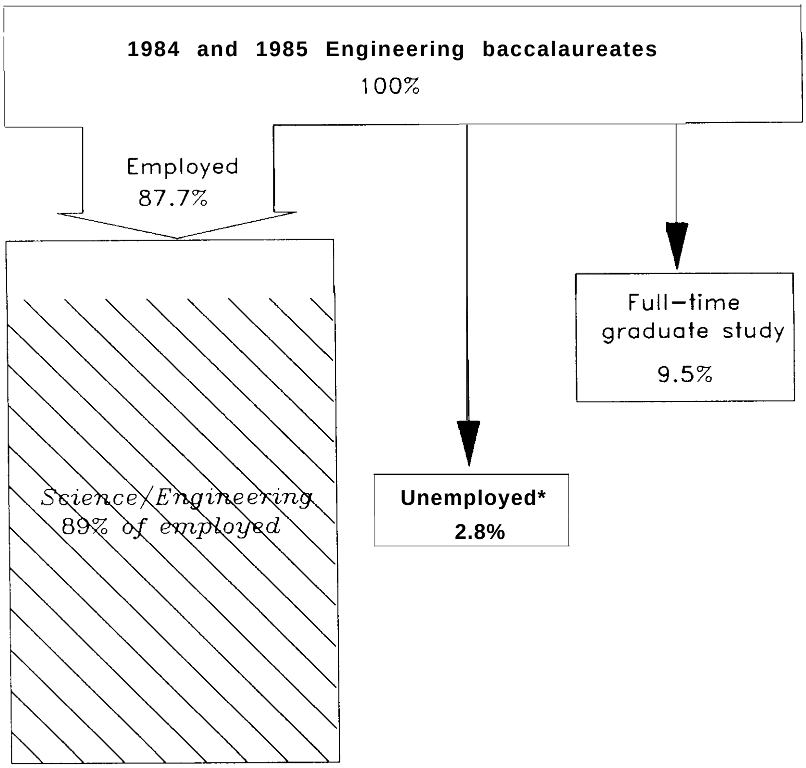
Ph. D. engineers, 1985



NOTE: n(Ph.D. engineers) = 65,900
Reflects latest available data.

SOURCE: National Science Foundation, U.S. Scientists and Engineers: 1988, Estimates, NSF 88-322 (Washington, DC: 1988), pp. 8-9; and National Science Foundation, Doctoral Scientists and Engineers: A Decade of Change, NSF 88-302 (Washington, DC: 1988), pp. 50-51.

Figure 4-2.-Career Paths of 1984 and 1985 Engineering Baccalaureates in 1986



*includes those not in labor force.

NOTE: Total graduates = 164,500
Part-time graduate study = 23,000 (14%)
Employed in industry = 110,900 (67%)

SOURCE: National Science Foundation, Characteristics of Recent Science and Engineering Graduates: 1986, NSF 87-321 (Washington, DC: 1987), pp. 1 3-15, 43-44, 47.

The supply of baccalaureate-level engineers does not distribute evenly, in numbers of students or talent, among engineering fields and specialties (see figure 4-3 and table 4-1). Students oversubscribe highly-visible, highly-paid fields such as electrical engineering and shun important but lower profile areas such as chemical and mining engineering. Electrical engineering has grown 250 percent and has been responsible for nearly one-half of the growth in engineering between 1977 and 1987, while civil and nuclear engineering have stagnated.

Many argue that the United States could better utilize and support its engineers, particularly with well-trained technicians and improved engineering management. Because engineering knowledge becomes outmoded, it is important to have a steady influx of newly-trained engineers and to refresh the knowledge of mid-career engineers through continuing education. Industry and the engineering community have a strong interest in lifelong education and retraining, as well as in undergraduate engineering education.

Perennial Themes: Quantity and Quality

The strength of the next generation of engineers depends on two things:

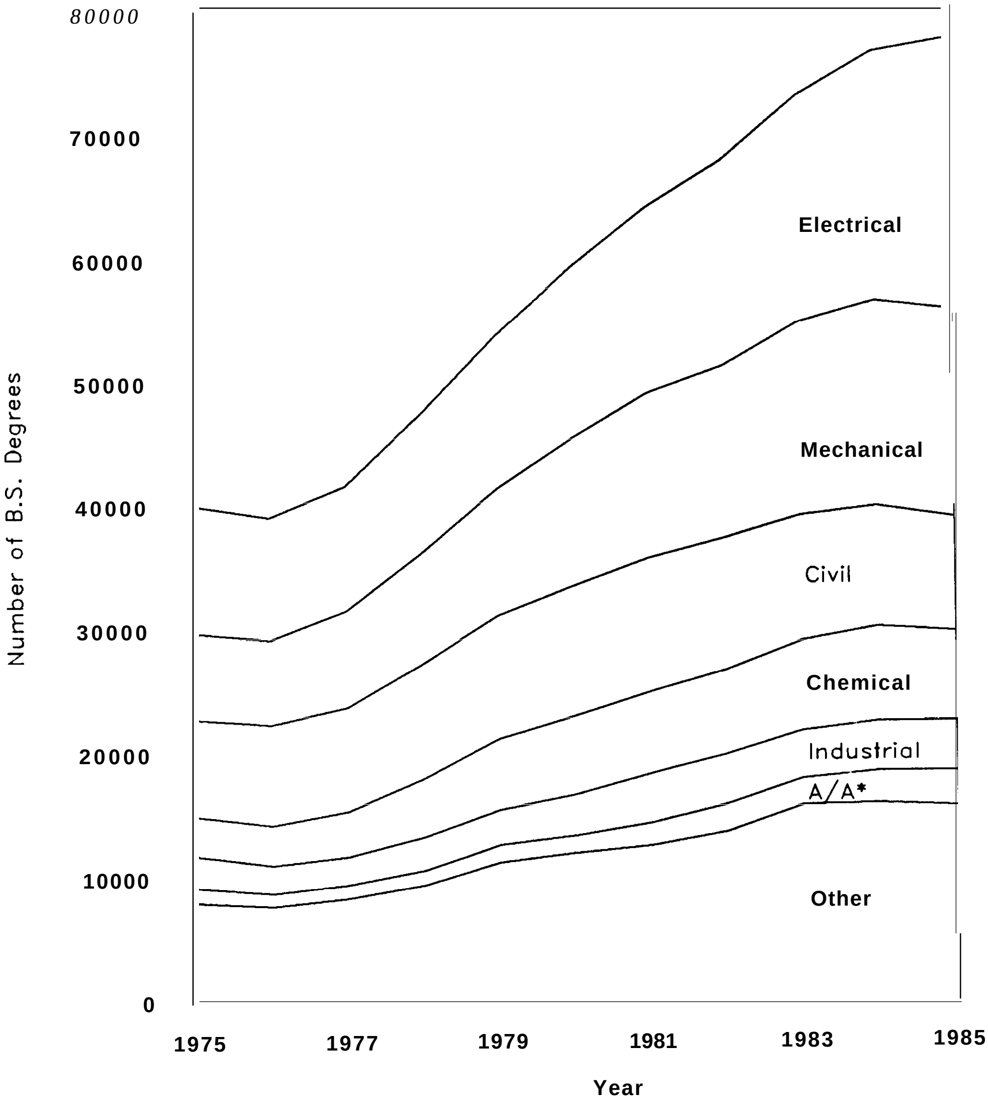
- students in the engineering pipeline, who shape the size and diversity of the supply of new engineers; and
- engineering institutions, whose capacity, facilities, faculty, and attitude determine the quality of engineering education.

The quality of engineering education deserves at least as much attention as the number of students. Quality depends on the structure of the curriculum, the academic preparation of students, and the capability of engineering institutions to provide effective faculty, facilities, equipment, and ties with industry.[2] Continuing concerns over the quality of engineering education, and its appropriateness for employers, students, and society as a whole have fueled longstanding issues over the structure and content of engineering education (see box 4-A and appendix D).

1987, NSB 87-1 (Washington, DC: National Science Foundation, 1987), pp. 64-65.

2. National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988). J.F. Coates, inc., *Forces Shaping the Future of Engineering Education* (Washington, DC: American Society of Mechanical Engineers, June 1987); Charles E. Hutchinson and Carol B. Muller, "Educating Engineers: In Praise of Diversity," *Issues in Science and Technology*, vol. 4, summer 1988, pp. 71-74.

Figure 4-3. -B.S. Degrees in Engineering, by Subfield, 1975-85



*~/~ = Aeronautical/astronautical

SOURCE: National Science Foundation, ~~Women and Minorities in Science~~ and Engineering, NSF 88-301 (Washington, DC: 1988), p. 197.

Table 4-1. — Growth Rate of Engineering B.S. Awards, by Specialty, 1977-87

	Growth rate 1977-87 (in percent)	Number of BS degrees awarded, 1987	Growth rate 1985-87 (in percent)
Computer	292	5,012	18
Aerospace	217	2,845	7
Electrical	156	25,198	14
Industrial	153	4,572	6
Mechanical	113	16,056	-6
ALL ENGINEERING	89	75,735	-3
Chemical	43	5,129	-29
Mining	15	628	-32
Civil	2	8,388	-11
Nuclear	-34	324	-24

SOURCE: Engineering Manpower Commission.

Universities report continuing, significant shortages of Ph.D. engineers for academic posts, due primarily to the strong industry demand (and accompanying high salaries) for engineers at all levels. Compared to the sciences, engineering has relatively few Ph.D.s; doctorate engineers make up only 3 percent of working engineers. Unlike Ph.D. scientists, they work mainly in industry. Ensuring an adequate, qualified supply of Ph.D. engineers is more problematic than sustaining undergraduates. Academia must compete with the high salaries, state-of-the-art equipment, and good working conditions of industry.[3] Substantial financial sacrifices usually must be made to undertake a Ph.D., in return for very modest financial gains in increased lifetime salary. The prestige of a Ph.D. in engineering is less than in the sciences. Overall, the rewards of obtaining an engineering Ph.D. are seen as small by many young U.S. citizens, so that foreign citizens have come to dominate U.S. graduate engineering programs and junior faculties.

Computer science, a hybrid of mathematics and engineering, is an applied science that in many aspects is closely allied with engineering. Much of the industry demand for computer scientists has been interchangeable with demand for electrical engineers. Other computer scientists do theoretical research. The newly-formed field of computer engineering is the fastest growing of all engineering specialties. As in engineering generally, over three-quarters of baccalaureate computer scientists go directly into industry, where salary offers are almost as high as those in engineering.

The Federal Government influences the demand for engineers through R&D initiatives, general R&D spending, and economic and fiscal policies which affect industry R&D spending and manufacturing. Policies in technology transfer, innovation, and university-industry relations affect engineers because of their crosscutting role in industrial R&D and developing new technologies into products and services.

As in science, the Federal Government has much greater influence on graduate education than on undergraduate education. Many engineering students, like students in all areas, depend on the Federal Government for financial support. Likewise, there is demand on the Federal Government to help bolster the capacity of colleges and universities to prepare engineers, particularly in terms of maintaining quality equipment,

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3. The National Science Foundation reports that in 1986 the median annual salaries of recent engineering baccalaureates (1984 and 1985 graduates) are $30,000 in industry and $19,600 in educational institutions — not including full-time graduate students. National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1986,* NSF 87-321 (Washington, DC: U.S. Government Printing Office, 1987), p. 83.

facilities, and faculty. The skewed demography of engineering — few women and minorities, but growing numbers of foreign students — has spurred calls for Federal action.

This chapter focuses on the many components of undergraduate engineering education. In addition to trends in enrollments and degrees, it is important to look at how the pool is formed and constrained by the curriculum, employer needs, and changes both in the engineering community and the wider culture.

Trends in Enrollments and Degrees

Engineering and computer science were the fastest growing areas of study in universities from the early-1970s to the mid-1980s. The largest increase has been in bachelor's engineering awards, which rose from 38,000 to over 77,000 between 1975 and 1985,[4] while baccalaureates in all fields grew less than 20 percent (see figure 4-4). During this boom, engineering bachelor's degrees went from 4.5 percent to 8 percent of all bachelor's degrees (see figure 4-5).

The surge in engineering baccalaureates ended in 1985, reflecting the downturn in the job market, particularly in the electronics and computer industries. Current undergraduate enrollments, coupled with the declining college-age population, indicate a substantial decline in conferred engineering baccalaureates through the 1990s.[5] Master's degrees continue their steady climb.

Engineering Ph.D.s, like those in the sciences, peaked in 1970-72 and then declined rapidly. The continuing decline in engineering Ph.D. awards relative to bachelor's awards in the 1970s testifies to the attractive job market for bachelor's- and master's-level engineers. Over the past 3 years, engineering doctorate awards have increased and regained their 1975 level. About 4,000 engineering Ph.D.s were awarded in 1987.[6]

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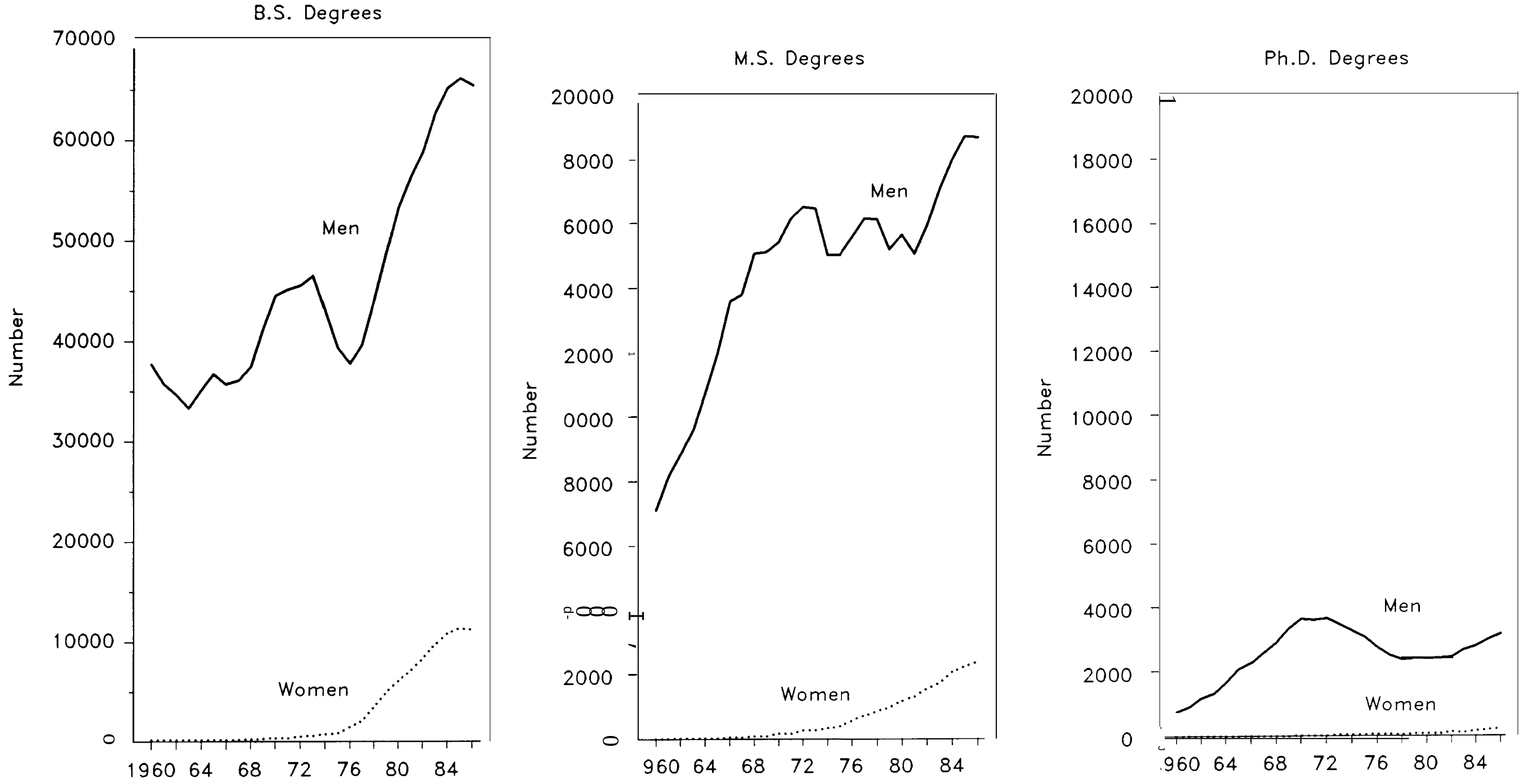
4. Engineering Manpower Commission, *Engineering and Technology Degrees* (Washington, DC: American Association of Engineering Societies, published annually). Unless otherwise noted, engineering degree data are from the Engineering Manpower Corn mission. The commission estimates at all degree levels tend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

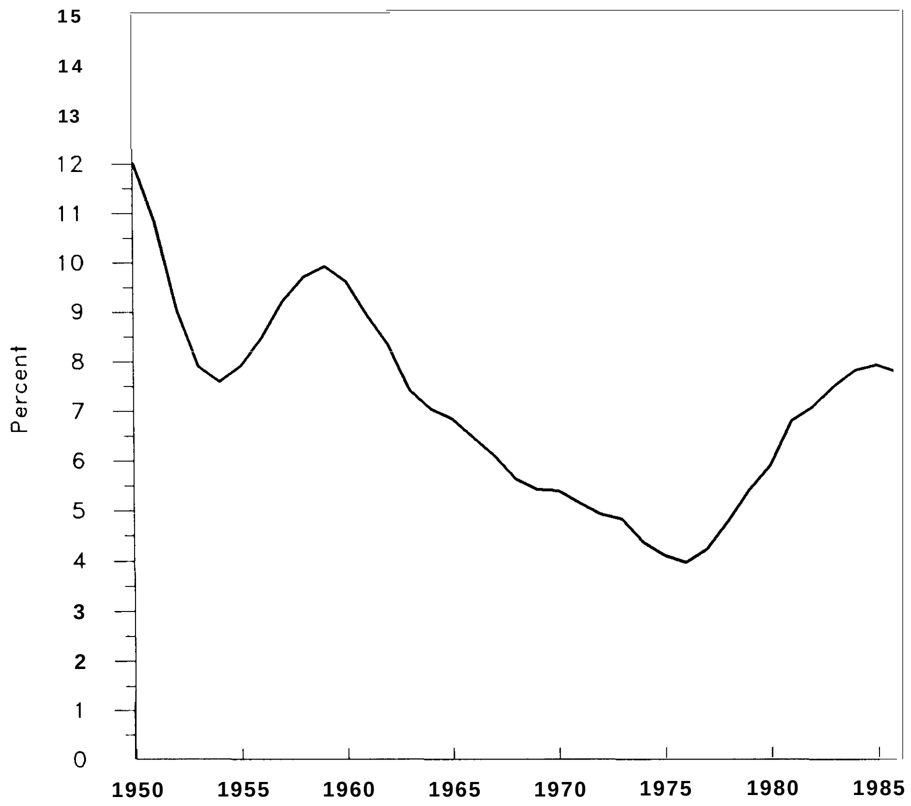
5. Commission on Professionals in Science and Technology, Washington, DC, unpublished data. Enrollment and degree data are from the U.S. Department of Education, National Center for Statistics; freshmen intentions from Cooperative Institutional Research Program, University of California, Los Angeles, *The American Freshman: National* Norms for Fall, 1985 (Los Angeles, CA: Higher Education Research Institute, December 1985).

Figure 4-4 –Engineering Degrees by Sex and Level, 960-86



SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," OTA contractor report, 1987, based on U.S. Department of Education data.

Figure 4-5.–Engineering Baccalaureates as a Percentage of All B.A./B.S. Degrees



SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945–1985," OTA contractor report, 1987, based on U.S. Department of Education data.

Graduate enrollments have been rising since 1978, signaling slight increases in engineering Ph.D. awards at least into the early-1990s. Although much of the recent increase has been due to foreign students on temporary visas, who now receive over 40 percent of engineering Ph.D.s, graduate enrollments of U.S. students have been rising as well, albeit very slowly.[7]

In 1986, over 41,000 B.S. degrees were awarded in computer science.[8] The field has boomed since the late 1970s. Similarly, between 1977 and 1985, the number of computer science graduate students rose more than 15 percent per year, from 9,000 to nearly 30,000.[9] In 1986, about 400 computer science Ph.D.s were awarded, compared to a few dozen 10 years before.[10] With a declining supply of mathematics Ph.D.s and a growing pool of computer science and computer engineering Ph.D.s, this growth may dwindle as the field matures.[11] Just under one-half of recent computer science Ph.D.s work in universities and colleges, with equal numbers in industry. Academic demand is still high and should continue to increase, though it has eased significantly from the near-crisis of the 1970s, when existing and potential faculty and graduate students flocked to lucrative jobs in industry.

Recruitment to the Undergraduate Pool

The size of the engineering pool is set early in the educational pipeline, more so than in other majors. A hierarchical and sequential curriculum, designed around the early-committed student, makes it difficult to enter from other majors. The gatekeeping function of high school mathematics preparation and college mathematics performance excludes most students. This intensive approach means that high school science and

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6. Engineering Manpower Commission data. However, about 40 percent of these are foreign students on temporary visas; this proportion has been increasing steadily.
7. National Science Foundation, *Academic Science/Engineering: Graduate Enrollments and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), p. 81.
8. U.S. Department of Education, Center for Education Statistics data.
9. All graduate students in all institutions. National Science Foundation, op. cit., footnote 7, p. 74. In the past few years, full-time enrollments have been rising faster than part-time enrollments. Among full-time students, foreign enrollments are continuing to rise faster than U.S. enrollments. Foreign students, including those on permanent visas, are now about 40 percent of full-time computer science enrollments.
10. National Research Council, Doctorate *Recipients From U.S. Universities* (Washington, DC: 1986). Twenty percent were awarded to foreign citizens, but most of those were on permanent visas.
11. The Computer Science Board, Committee on Research Funding in Computer Science, *Imbalance Between Growth anal Funding in Academic Computer Science: Two Trends Colliding* (Washington, DC: April 1986), pp. 8-9.

mathematics preparation strongly governs first the choice of engineering and then the persistence of those students who choose engineering majors.

Most freshman engineers choose engineering during the junior and senior years in high school.[12] While mathematics and science are taught in high school as "foundation" courses for technical careers, there are very few "pre-engineering" programs — and they are often vocationally-oriented. Most are targeted to minorities or the gifted.[13] Students plan engineering majors on the basis of other influences, such as relatives, parents of friends, movies, television programs, books, imagination, and perceptions (accurate or not) of a job market that offers attractive starting salaries. These influences are poorly understood.[14]

Freshman interest in engineering reflects trends in the job market, and anticipates the supply of baccalaureates a few years down the road. Interest in engineering peaked in 1982, when over 12 percent of all college freshman planned to major in engineering (B.S. degrees peaked in 1985-86). Among 1987 freshman, fewer than 10 percent were interested in engineering majors.[15] Freshman interest in computer sciences followed a

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12. Report of the Task Force on the Engineering Student Pipeline, "Findings and Recoin mendations," *Engineering Education*, vol. 78, May 1988, pp. 778-780.
13. See Gillian F. Clark, "Pre-College Programs Key to Minority Engineering Efforts," *Black Issues in Higher Education*, Oct. 15, 1987, pp. 9-10; and National Action Council on Minorities in Engineering, *Pre-College Program* Directory(New York, NY: 1985). Two examples: Philadelphia Regional Introduction for Minorities to Engineering (PRIME) offers enrichment, student internships, counseling, field trips, industry programs, and publicizes educational success stories for junior high and high school minority students in southeastern Pennsylvania. Alexander Tobin and Richard Woodring, "PRIME: A Model Precollege Minority Program," *Engineering Education*, May 1988, pp. 747-749. The Department of Energy's Prefreshman Engineering Program (PREP) awards money to colleges and universities for sum mer research and instruction in mathematics, science, and engineering for junior high school girls and minorities. There is extensive cost-sharing with local industry; the 1985 budget was $280,000. In 1985 this program reached over 2,700 students. Students are selected by school teachers and counselors, primarily on the basis of interest and ability. About two-thirds of students who participate in PREP go on to pursue science or engineering in college. U.S. Department of Energy, *University Research & Scientific Education Programs of the U.S. Department of Energy*, DOE/ER-0296 (Washington, DC: September 1986), p. 9.
14. See U.S. Congress, Office of Technology Assessment, *Elementary and Secondary* Education *for* Science and Engineering, OTA-SET-TM-41 (Washington, DC: U.S. Government Printing Office, December 1988), chs. 1, 5. Engineering-related programs in and outside of school might augment the pool of students interested in and prepared for engineering majors in college.
15. Cooperative Institutional Research Program, University of California-Los Angeles, *The American Freshman* (Los Angeles, CA: Higher Education Research Programs, published annually).

similar, but more exaggerated, rise and fall. Both trends show pronounced differences when students are disaggregate by sex (see figure 4-6).

The Relation Between Salaries and Supply

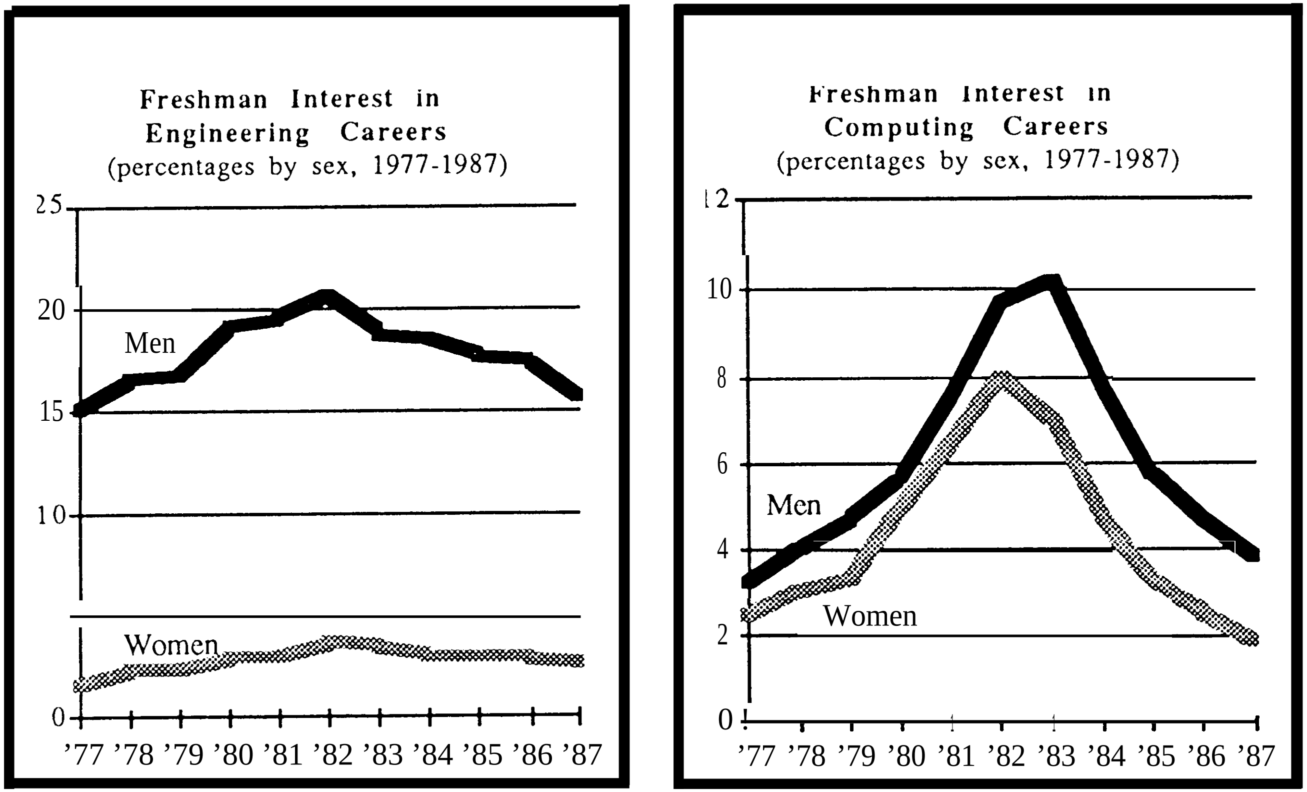
As with other fields, engineering attracts students for a combination of reasons, ranging from innate interest and family pressures to a desire for a stable job and good pay. Many cite the high salaries for engineers as a leading reason for many students' interest. Engineers receive higher starting salaries than any other baccalaureate-level specialist, about $29,000 (compared to $21,000 for the average college graduate).[16] The substantial salary advantage for engineers has been longstanding and has been unchanged in real terms. For a decade beginning in 1973, real salaries rose faster than average, but have since declined. The stability of starting salaries over the long term suggests that, despite temporary variations, supply and demand are relatively well matched within the 4 to 5 years it takes to produce a B.S. "generation."

Generally the financial profile of undergraduate engineers resembles that of other students. Engineering students are slightly more likely than science students to have loans, and less likely to use grants only. Engineering students who borrow tend to acquire slightly higher than average debt, possibly in part because they anticipate higher than average salaries. The difference in loan burdens is not great, however (especially taking into account the higher salaries of engineers), and debt does not affect the choice of undergraduate major. There is no good evidence that higher loan burdens are driving students to choose higher-salaried fields such as engineering.[17]

To the extent that money figures into students' goals, higher and more stable pay for engineers, whether in academia, government, or industry, influences their career choice.[18] Freshmen planning to major in electrical engineering, chemical engineering> '

16. *Manpower Comments,* January/February 1988, p. 25.
17. Edward P. St. John and Jay Noell, 'Student Loans and Higher Education Opportunities: Evidence on Access, Persistence, and Choice of Major," prepared for the Fourth Annual NASSGAP/NCHELP Research Network Conference, June 3, 1987; and Applied Systems Institute, Inc., 'Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates,' OTA contractor report, 1987, based on Recent College Graduate Survey data. As long as B.S. engineering salaries remain strong, students respond well without additional financial incentives. While engineering students are more likely than others to do cooperative work-study during college, such programs are not a significant source of funds for most students.
18. Kenneth C. Green, personal communication, 1987. Data are from the Cooperative Institutional Research Program.

Figure 4-6.–Freshman Interest in Engineering and Computing Careers, by Sex, 1977-87



SOURCE: Cooperative Institutional Research Program, The American Freshman: National Norms for Fall 1987 (Los Angeles, CA: University of California, Los Angeles, December 1987), p.6.

computer science are more job- and money-oriented in their college plans than other freshmen, including other science/engineering majors, and are more likely to cite job opportunities and high salaries as very important reasons for attending college.

Attrition

Attrition of undergraduate engineering majors, like science majors, is significant (around 20 to 30 percent), but varies greatly by campus, and with trends in the job market.[19] During the engineering boom of the late-1970s, transfers into engineering compensated for attrition. Attrition is substantially lower for Asians, higher for women and Hispanics, and even higher for Blacks (see figure 4-7). Attrition is compounded when students need 4.5 or 5 years, a not uncommon period, to complete the baccalaureate in engineering.

Attrition, however, can be reduced. Effective preparation and retention programs have been demonstrated with women and minorities, and it is likely that such programs can be applied to the majority of the population. Few universities and colleges have recruitment and retention programs for students wishing to choose engineering majors after the freshman year. Transfers into engineering from 2-year institutions seem to provide a quick response to ups and downs in the job market, but national data on this phenomenon are lacking.[20]

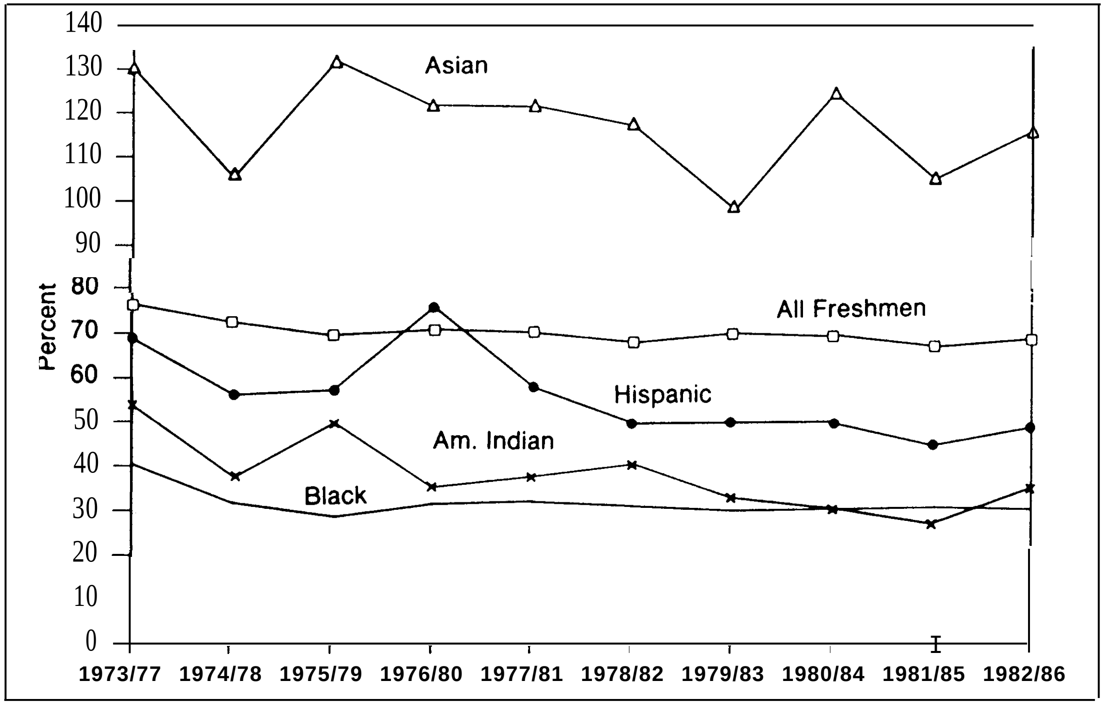
Expanding and Diversifying the Pool of Engineers

Engineering is a large and diverse profession. Educators concerned about bolstering the supply of young engineers look to both talented white male students entering other fields, and to women and minorities, groups that have so far been poorly represented in engineering. Recruitment strategies can generally be applied to all students; minorities and women must, however, be reached early and given stronger academic preparation, particularly in mathematics. Recommendations to expand and diversify the pool of engineering students are listed in box 4-B.

19. Betty M. Vetter, ‘Demographics of the Engineering Student Pipeline," *Engineering Education,* vol. 78, No. 8, May 1988, pp. 737-739, based on Engineering Manpower Commission data.

20. The growth of ‘3+2” programs, which funnel students from liberal arts colleges into engineering programs, also highlights the transfer function. Again, however, national data are elusive.

Figure 4-7.-Retention Rates of Engineering Freshmen, 1973/77– 1982/86



NOTE: Asian student retention rates greater than 100% reflect the fact that the drop-out rate among freshmen and sophomores is less than the input at the junior year from two-year institutions.

SOURCE: Betty M. Vetter, “Demographics of the Engineering Student Pipeline,” <u>Engineering Education</u>, vol. 78, No. 8, May 1988, p. 739.

Women

Women have made much faster gains in engineering than in any other field, largely because their historic participation rate was miniscule (see figure 4-8). Women earn about 15 percent of engineering baccalaureates, up from less than 1 percent in 1970. Engineering and computer science have gained popularity at the expense of the life and social sciences. Gains have also been significant at the master's level and, to a lesser extent, at the Ph.D. level, where women earn about 7 percent of science and engineering Ph.D.s. Gains vary by field; female engineers tend to concentrate in chemical, petroleum, and industrial engineering, and are less likely to choose, for example, electrical engineering.

Current trends suggest a slowing of these gains. Freshman engineering enrollments of women have leveled off at about 16 percent. Despite the plateau, the rapid gains were unprecedented. Understanding this change could well illuminate the mechanisms of career selection at work in the vast population of college students who ignore or are not welcomed by certain fields.[21] This was the case for women in engineering before the 1970s.

Gains for women have been slow in engineering employment, especially in faculty jobs. The small number of women in tenure-track engineering faculty positions, between 100 and 200 nationwide, indicates the persistence of barriers.[22] At nearly all levels of education and experience, there is a salary bias against women. For the most recent graduates, however, women and men receive equivalent starting salaries, in part probably due to sustained years of strong demand for engineers.[23]

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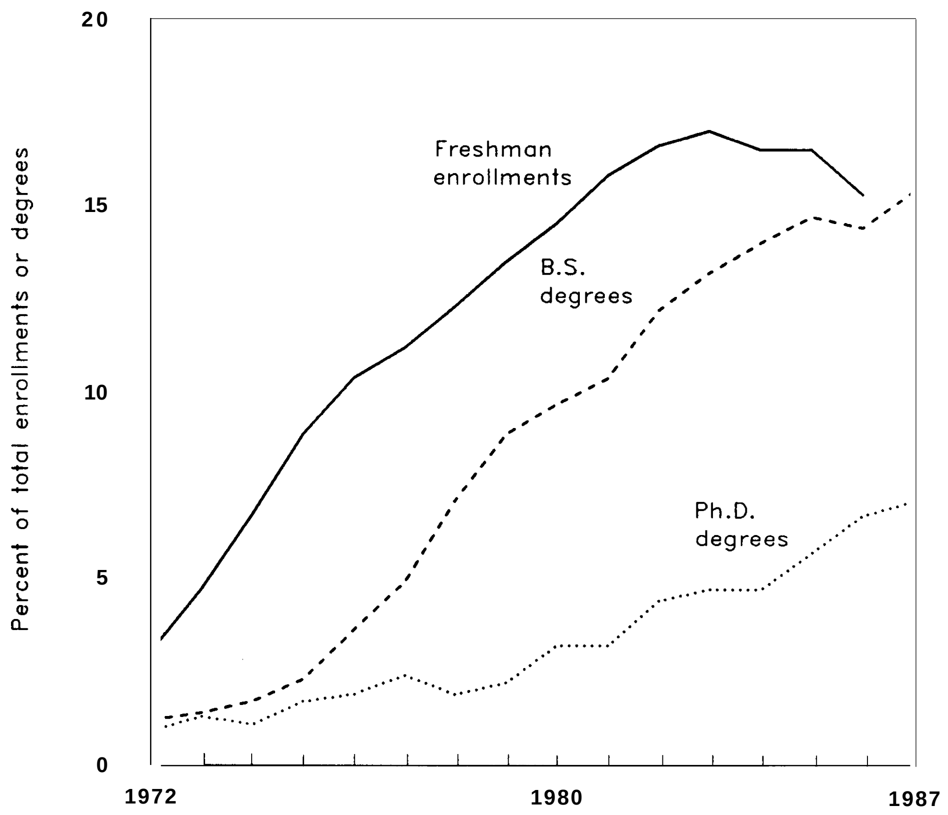
21. Carolyn M. Jagacinski et al., 'Factors Influencing the Choice of an Engineering Career/' *IEEE* Transactions *on Education, vol. E-28,* No. l, February 1985, pp. 36-42.
22* Attitudes of male engineers — especially those with 5 or more years of work experience, no Ph.D., and little daily contact with female engineers — toward female engineers in the nonacademic workplace tend to be negative. Anil Saigal, "Women Engineers: An Insight Into Their Problems," *Engineering Education,* December 1987, pp. 194-195; William K. LeBold, "Women in Engineering and Science: An Undergraduate Research Perspective, " *Women: Their Underrepresentation and Career Differentials in Science and Engineering,* Proceedings of a Workshop, Office of Scientific and Engineering Personnel, National Research Council (Washington, DC: National Academy Press, 1987), pp. 49-98.
23. The National Science Foundation reports that among recent engineering baccalaureates (1984 and 1985 graduates who were employed full time, not including full-time graduate students) men and women had identical annual salaries. By comparison, in all scientific fields, men receive salaries several thousand dollars greater than those women receive. National Science Foundation, op. cit., footnote, 3 p. 82. An industry

Figure 4-8.-Women in Engineering, 1 972–87



SOURCE: Engineering Manpower Commission data.

Computer science has become an increasingly common field of graduate study and employment for women. Nine percent of employed computer science Ph.D.s are women, the highest proportion outside the social and biological sciences. In science and engineering, women earned 16 percent of U.S.-earned Ph.D.s and one-third of the bachelor's degrees in 1986.[24] One in five full-time graduate students in the United States is a woman (the percentage is higher, perhaps one-third, for U.S. students, since most foreign students are male).[25]

Minorities

Blacks and Hispanics have made slow inroads into engineering. Although minorities are interested in engineering majors, they are generally poorly prepared academically and often lack the study habits needed to succeed in the unfamiliar environment of college. Their attrition is much higher than that of whites or Asians; about one-half of Hispanic, and one-third of Black engineering freshmen complete undergraduate engineering programs, compared with an average for all freshmen of 70 percent. Together, Blacks, Hispanics, and Native Americans are about 5 percent of engineers. Asian-Americans are an additional 7 percent. The small increase in the Blacks' and Hispanics' share of engineering degrees dwindles when compared to the concurrent rise in the proportion of Blacks and Hispanics among the college-age population (see table 4-2). Blacks and Hispanics are scarcer at the Ph.D. level in engineering than in the sciences; perhaps a dozen Blacks and two dozen Hispanics receive engineering Ph.D.s each year. The story is similar in computer sciences.

Asian-Americans have become a much larger proportion of undergraduate engineering majors than their representation in the general population (about 1 percent) would lead one to expect. Most of these degree recipients are foreign-born Asian immigrants. Asian-Americans (including foreign-born Asians on permanent visas) receive over 13 percent of engineering Ph.D.s granted to U.S. citizens.

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perspective on salary differentials is also instructive. As part of an annual profile, Robert R. Jones ("R&D Industry Developing An Entirely New Look," Research & *Development*, vol. 30, May 1988, pp. 78-80) reports that ". . . the highest median salary for women (women in industry) remains below the lowest for men (men in universities) by 17.1%.'[1] In some areas, the "entirely new look' 'remains all too familiar.

24. National Research Council, op. cit., footnote 10. Women earned only 12 percent of all Ph. D.s, since almost all foreign students are male. Bachelor's data are from the U.S. Department of Education, National Center for Statistics.

25. National Science Foundation, op. cit., footnote 9, p. 41.

Table 4-2. —Engineering Degrees, by Level and Race/Ethnicity, 1987
(in percent)

	B.S.	M.S.	All Ph.D.s	U.S. Ph.D.s 1986
Blacks	2.9	1.5	0.4	1.4
Hispanics[a]	3.1	1.6	0.6	2.0
American Indians	0.2	0.1	0.1	0.3
Asian-Americans	6.7	7.3	5.6	15.2
ALL MINORITIES	12.9	10.5	6.7	19.0[b]

a Includes degrees awarded by the University of Puerto Rico (up R). If these data are not included, Hispanics are 2.4% of B.S. degrees. UPR data would not change M.S. or Ph.D. results.

b U.S. minorities as a percent of engineering Ph.D.s awarded to U.S. citizens* "U* S*" includes foreign citizens on permanent visas.

SOURCE: Richard A. Ellis, "Engineering and Engineering Technology Degrees, 1987, " *Engineering Education, vol. 78, No. 8,* May 1988, p. 785.

A supportive campus environment and institutional commitment to minorities are particularly important for helping minorities graduate.[26] Special support programs can substantially reduce attrition for Blacks and Hispanics in engineering.[27] Most programs have a strong campus base, but depend on government and private funds as well as university support. Successful programs provide peer support, tutoring, and community-building among minority students. All emphasize the importance of precollege preparation, call for consistent retention efforts from middle school through college, and high school career guidance by engineering professional societies.[28] Today, there are indeed success stories (see box 4-C).

Ten institutions produce one-third of Black B.S. engineers; three of these are historically Black colleges or universities. The University of Puerto Rico produces over 20 percent of Hispanic engineers; 20 institutions produce half of the rest.[29] At least ‘n the near term, the concentration of minority engineering students in a small number of institutions argues that a few specially targeted and well-supported intervention programs could reach a large proportion of minority students.

Latecomers to engineering are another potential source of engineers. Significant numbers of engineers decide to enter engineering <u>during</u> college; in periods of high demand, as many as one-quarter of B.S. graduates.[30] Most of these enter from other

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26. Richard C. Richardson, Jr. et al., “Graduating Minority Students,’' *Change*, May/June 1987, pp. 20-27; and Edmund W. Gordon, “Educating More Minority Engineers, ” Technology Review, July 1988, pp. 69-73.

27. Ray Landis, "The Case for Minority Engineering Programs," Engineering *Education*, May 1988, pp. 756-761. For Black freshmen engineers at the University of California, attrition (out of engineering or school altogether) after 3 years was 87 percent; for Blacks in the Minority Engineering Program, attrition was 36 percent. The Minority Engineering Program has had similar success with Hispanic students.

The private National Action Council for Minorities in Engineering (NACME) is the leader in coordinating and disseminating information on minorities in engineering and intervention programs. NACME's $1.1 million funding for the first 4 years came from the Sloan Foundation. The next 4 years gathered corporate support and eventually some National Science Foundation funding. NACME and most intervention programs also receive substantial in-kind support from corporations (e.g., faculty loans) and colleges and universities.

28. National Academy of Engineering, *Engineering Education and Practice in the United States: Engineering Infrastructure Diagraming and Modeling* (Washington, DC: National Academy Press, 1986); and National Academy of Engineering, *Engineering Undergraduate Education* (Washington, DC: National Academy Press, 1986).

29. For a review of national minority engineering programs, and data on top-producing institutions of minority engineers, see “Special Report: Engineering Education,” *Black Issues in* Higher Education, vol. 4, No. 15, Oct. 15, 1987, pp. 9, 12-15; and *Engineering Education, vol. 78,* May 1988.

scientific or technical majors. Despite evidence of this potential for recruitment during college, engineering curricula are aimed at students who come to college having chosen the engineering major. Little effort is made at the college level to attract nonengineering majors, though engineering educators recognize this as a key issue and are now mobilizing to address it.[31]

Foreign Engineering Students

The influx of foreign students to American universities is particularly apparent in engineering. Foreign students have received a steady 7 to 9 percent of bachelor's engineering degrees since the mid-1970s. Their share of master's degrees increased slightly during the 1970s to around 25 percent, which has held steady since 1980. Foreign students are much more likely than U.S. students to continue for Ph.D.s. Over 40 percent of recent engineering Ph.D.s have been awarded to foreign students on temporary visas, up from 30 percent in 1975 (see figure 4-9).[32] About 70 percent of the foreign students who receive engineering Ph.D.s are Asian.[33]

The high demand for engineers has made it more attractive and easier for foreign students to study and work in the United States. About one-half of foreign engineers (at all degree levels) stay on to work in the United States after graduation.[34] The shortage of engineering faculty has made university and college departments particularly dependent on foreign Ph.D.s. The proportion of foreign engineers among young faculty (age 35 or younger) has risen from 10 percent to nearly 50 percent since 1975.[35]

Foreign students have also joined the rush to computer science. Foreign students on temporary visas received nearly one-third of the computer science Ph.D.s awarded in

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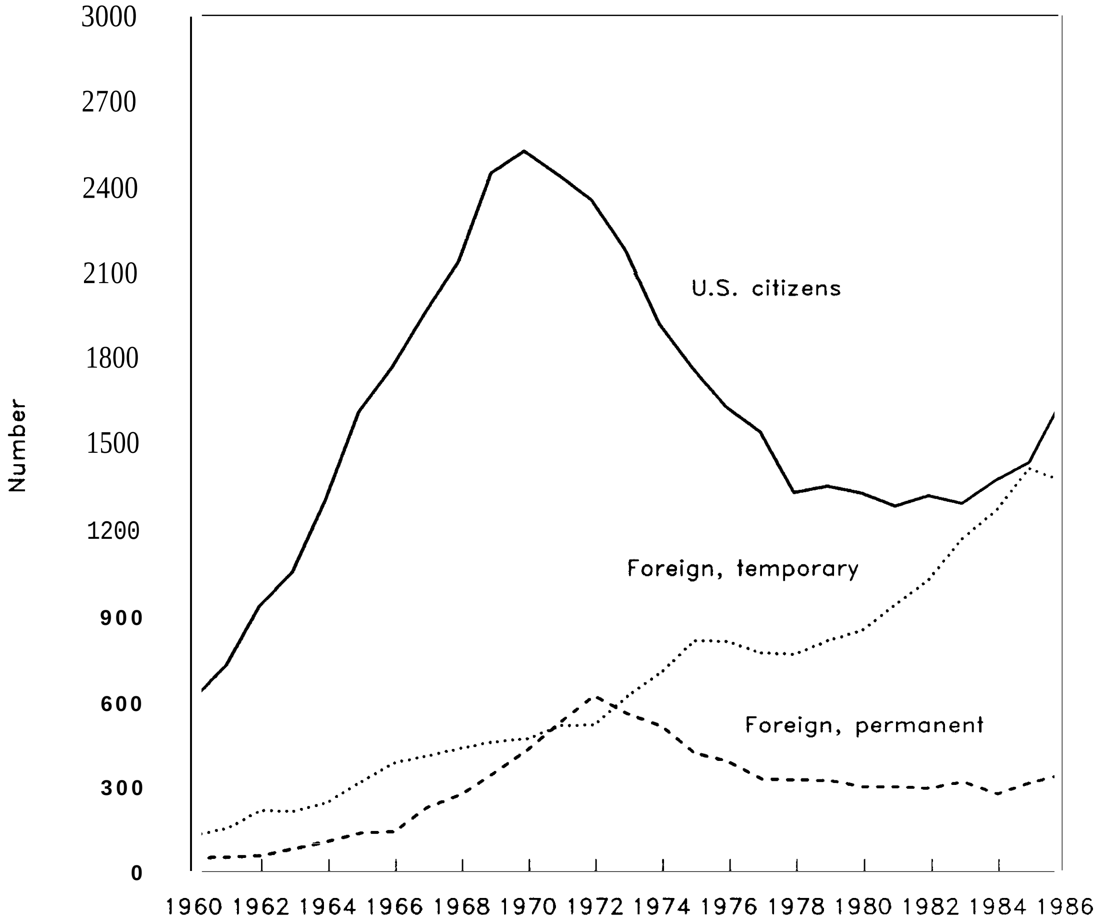
30. Anne Scanley and Engin Holstrom, Government-University-Industry Roundtable, National Academy of Sciences, personal communication, September 1987. Analysis of the 1984 followup on the 1980 Cooperative Institutional Research Program, University of California, Los Angeles, data on freshmen show that 20 to 25 percent of engineering majors in colleges and universities were recruited to that major during college.
31. J. Ray Bowen, "The Engineering Student Pipeline," Engineering *Education*, vol. 78, May 1988, pp. 733-734.
32. National Research Council, op. cit., footnote 10.
33. National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook* (Washington, DC: December 1986), p. xiii. The share of U.S. citizens receiving Ph.D.s increased in 1986.
34. Michael G. Finn, Oak Ridge Associated Universities, "Foreign National Scientists and Engineers in the Labor Force, 1972 -1982," June 1985, p. 5.
35. Engineering Manpower Commission survey, in Vetter, op. cit., footnote 19, p. 739.

Figure 4-9.-Engineering Ph.D. Awards by Visa Status, 1960-86



SOURCE: National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook, NSF 86–305 revised (Washington, DC: 1986), p. 96.

1986, up from 11 percent in 1977.[36] Most foreign computer scientists --at both the bachelor's and Ph.D. levels — remain to work in the United States, more than in any other field.[37] Foreign computer scientists are important as new hires in the electronics and computer industries as well as academia. In Silicon Valley companies, they may constitute as much as one-third of the work force.[38] Foreign nationals comprise over one-third of all university computer science faculty, the highest ratio among all fields of science or engineering.

Employers and universities testify to the high quality of foreign students and engineers.[39] However, the large numbers of foreign students and faculty have raised concerns in the engineering education community. Some foreign faculty, for example, have been said to discriminate against women, reflecting their cultural backgrounds. (Of course, native engineering faculty are not always free of such prejudice either.) The Department of Defense (DoD) has also expressed concern about adequate supplies of American citizens to work as engineers on defense projects. For this, DoD has taken initiatives to bring more women and minorities into the talent pool.[40]

THE QUALITY ISSUE IN ENGINEERING EDUCATION

The quality of engineering education rests mainly in the hands of the institution. Each engineering college oversees its own admissions, curriculum, student programs, faculty, facilities, and laboratories. In other words, institutions delegate (or concede) responsibility for executing quality standards to disciplines, departments, and individual faculty.[41]

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36. National Research Council, Doctorate Recipients *From U.S. Universities, Summary Report 1986* (Washington, DC: National Academy Press, 1987).
37. U.S. Congress, General Accounting Office, *Plans of* Foreign Ph.D. Candidates: Postgraduate *Plans of U.S.* Trained *Foreign* Students *in* Science/Engineering, GAO/RCED-86-102FS (Washington, DC: February 1986), p. 3.
38. National Science Foundation, op. cit., footnote 33, p. 75, charts 5.1 and 5.2.
39. For example, Stanford S. Penner, "Tapping the Wave of Talented Immigrants, 't *Issues in Science and Technology,* vol. 4, spring 1988, pp. 76-80; and National Research Council, *Foreign and Foreign-Born Engineers: Infusing Talent, Raising Issues* (Washington, DC: National Academy Press, 1988).
40. Two major initiatives include the Center for the Advancement of Science, Engineering and Technology, a Department of Defense-sponsored project which is compiling information on successful intervention programs; and the National Consortium for the Physical Sciences, a consortium of Federal agencies, major corporations, and universities that is working to increase support and research opportunities for women and minority graduate students.
41. Guidance from engineering societies, especially the American Society for

Except for national missions such as the Apollo program, the Federal Government has had little direct role in engineering education.[42] While the project-based programs of the mission agencies have had massive effects on the production of engineers, little money has been directed toward science and engineering education per se. The concern with engineering problems, especially at DoD, the National Aeronautics and Space Administration, the Department of Transportation, and to a lesser extent the Department of Energy and the Environmental Protection Agency, has underwritten the support for human resources. In contrast with the founding of the National Science Foundation's (NSF) Engineering Directorate (and the addition of engineering to its charter), engineering research centers and education have been formally recognized.

Faculty

Attracting and keeping good faculty is critical for engineering schools. Because of strong industrial demand for engineers in the past 10 years, universities and colleges seeking faculty to serve high undergraduate enrollments face a continuing shortage of Ph.D. engineers interested in academic positions, particularly in fast-growing fields such as electrical and computer engineering. The American Society for Engineering Education (ASEE) reports that about 9 percent of the 20,000 faculty posts are unfilled. And anticipated high retirements (in most academic fields) in the 1990s should again increase demand. Universities would like to be able to hire more U.S. faculty than are available.[43]

42. As recently as 1982, no Federal agency targeted funds specifically for undergraduate engineering education. According to a General Accounting Office analysis, a total of 38 programs in 11 agencies spent $240 million on engineering education in fiscal year 1981, but more than 80 percent of this was in the form of student loan guarantees and a little over 10 percent went to the Merchant Marine and Coast Guard Academies. U.S. Congress, General Accounting Office, *No Federal Programs are Designed Primarily to Support Engineering Education, But Many Do, GAO/PAD-82-20* (Washington, DC: May 14, 1982).

43. A.S. Wilke and W.A. Shaw, "The Faculty Shortage: Comparing National and Local Data," *Engineering Education,* January 1988, pp. 233-235. The interplay of supply and demand, and inferences about quality that arise at times of imbalance, is discussed in National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988). The new Federal law prohibiting retirement due to age is raising anxieties in universities about differential impacts on faculty hiring by field.

Faculty and graduate student increases have not kept pace with increasing enrollments, and the faculty-to-student ratio has declined. In the engineering boom between 1973 and 1983, undergraduate enrollments grew 80 percent while faculty numbers grew 10 percent. ASEE recommends ratios of 12 or 14 to 1 for undergraduate engineering education, which would require a 20 to 25 percent increase in current faculty numbers.[44] Shortages are worst at predominantly undergraduate institutions.[45] In response to the demand for faculty, engineering schools are using more adjunct, industrial, part-time, and other nontraditional faculty.[46]

Methods of attracting engineers into academia now include, for example, NSF's Presidential Young Investigator awards, which encourage industry matching funds. Some States and universities created special salary schedules or add-ens for engineering faculty; these helped recruit and retain faculty. Faculty development – career long learning— is often cited as a priority for engineering professors.[47]

Access to Equipment and Facilities

State-of-the-art equipment is particularly important in engineering education, and contributes significantly to its high cost.[48] Since 1985 engineering faculty cite laboratory equipment and building facilities as two of their most pressing problems.[49] This is both a catch-up problem, to make up for past underinvestment, and a continuing problem because of the rising costs of equipment and maintenance.

Equipment problems vary by field. They are chronic in manufacturing engineering, where equipment comes in large and expensive pieces. Universities may tailor their course offerings according to availability of certain kinds of low-cost or donated

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44. W. Edward Lear, *The Quality of Engineering Education Programs* (Washington, DC: American Society for Engineering Education, 1986), p. 139.
45. Paul Doigan and Mack Gilkeson, "Engineering Faculty Demographics: ASEE Faculty & Graduate Student Survey, Part II, *Engineering Education,* January 1987, p. 208.
46. Ibid., p. 212.
47. American Society for Engineering Education, A *National Action Agenda for Engineering Education* (Washington, DC: 1987), pp. 18-22.
48. The American Society for Engineering Education in 1986 estimated $8,400 for laboratory costs for educating a B.S. engineer, including for personnel, operating costs, and amortized capital cost. Lear, op. cit., footnote 44, p. 141.
49. According to a 1985 American Society for Engineering Education survey, reported in Doigan and Gilkeson, op. cit., footnote 45, p. 212. For 1987 survey results, see Paul Doigan and Mack Gilkeson, "Who Are We? Engineering and Engineering Technology Faculty Survey, fall 1987, Part 11, '1 *Engineering Education,* vol. 78, November 1988, pp. 109-113.

equipment; the result may be significant gaps in course offering where equipment is not available.

In engineering as in the sciences, most laboratory equipment is obsolete and in extremely short supply, classroom and laboratory space is inadequate, and buildings often need renovation or replacement. The problems are particularly acute at teaching-oriented institutions that do not receive extensive corporate or Federal research support; these institutions produce one-half of all B.S. engineers. Even where up-to-date equipment is available as a result of corporate gifts, funds to maintain, insure, or repair it are often lacking. The easing of enrollment pressure in the last 3 years does not resolve the problem. A very large number of engineering institutions are still training students with little hands-on experimental experience, in overcrowded laboratories, using equipment so obsolete it bears no resemblance to what the students will encounter when they graduate.

Increased spending on engineering equipment in the past few years has mitigated but not eliminated the immediate problem.[50] Maintenance and new needs will continue to press for permanent changes in funding of university equipment. These needs impinge on all areas of science; engineering is especially affected because it is so equipment-intensive.

The unanimous recommendations of recent studies are for major Federal funding and incentives that would sharply increase State and corporate contributions to institutions whose primary mission is undergraduate engineering education. One engineering community study estimated a need to double laboratory space and spend nearly $3 billion for instructional laboratory equipment to match to the peak quality levels of 1972, and defray a current annual maintenance cost of about $30 million.[51]

Computers and Communications Technologies

Computers and computer-based equipment have become integrated into day-to-day engineering teaching and laboratories, and have created an entirely new education industry of televised, videotaped, and telecommunicated instruction.[52]

50. National Science Board, op. cit., footnote 1, pp. 80-84 and 256-263.
51. Lear, op. cit., footnote 44, p. 140.
52. Ibid., pp. 73-122.

Computers and Undergraduate Engineering Education

Computer and communications applications in engineering are diverse. They include decision and design aids, desktop computers, teaching aids, flexible manufacturing systems, computer-aided design and engineering workstations (CAD/CAM/CAE), graphics, computerized sensors and nondestructive testing, simulation, computerized machine tools and robotics, supercomputers, sophisticated portable calculators, instructional video, and communication networks.

Intelligent engineering tools demand human partners with new skills and roles, emphasizing problem recognition, unusual problem solving, visualization, flexibility, information evaluation and synthesis, and decisionmaking. Networking may extend the engineer's role in communicating with management, the public, regulators, foreign customers and sources, and sales personnel. These new needs demand changes in the education of engineers, technologists, and technical managers. Students must understand and practice with the tools they will be using in the future.

The current pressing concern is adequate student access to modern workstations and computer-based equipment. Universities have difficulty equipping and maintaining their classrooms, offices, and laboratories and rewiring buildings, despite special Federal equipment funding and industry donations. Arranging access to industry equipment through special programs or cooperative education has not proved easy or sufficient. Federal tax incentives have helped but not inspired industry donations; student fees are insufficient to cover costs; States have had limited effect.[53] In the longer term, new issues may arise as changes in engineering jobs and computer-based training restructure the engineering curriculum.

Distance Learning

Long-distance delivery of education through video recordings and telecommunications networks opens new arenas for engineering education. Distance learning is particularly important for part-time, advanced students at the master's level, and for continuing engineering education. Electronic instruction takes several forms. On campus, televised courses can reach more students at a variety of times, easing

53. U.S. Congress, Office of Technology Assessment, *Technology, Innovation, and Regional Economic Development*, OTA-STI-238 (Washington, DC: U.S. Government Printing Office, July 1984).

overcrowding in engineering classrooms. It provides employees at job sites with remote access to instruction emanating from universities, companies, and third parties. Instruction can be real time and interactive, or recorded for later use. Video and electronic technologies make access to education convenient, flexible, broader, and less expensive. They make possible more diverse, up-to-date, tailored courses and permit certain economies of distribution.

The Association for Media-Based Continuing Education for Engineers (AMCEE) was founded as a consortium in 1976, with funds from NSF and the Sloan Foundation, to increase the national effectiveness of continuing education for engineers. Membership has grown from 12 to 33 universities, serving thousands of engineering students; the current catalog lists more than 550 video courses. Building on this success, in 1982 the National Technological University (NTU) was created (see box 4-D). in addition to courses by satellite, NTU offers special symposia, teleconferences, and other services.

Electronic instruction is spreading. In 1986 nine major programs using instructional television to provide M.S. programs in engineering disciplines were in operation or under development. Operated by public and private universities, the programs used various delivery methods to reach part-time students, usually at their job sites. More than 40 regional systems are in operation today. About two dozen major universities, in the past 20 years, have awarded more than 3,500 M.S. degrees to engineers who complete degree requirements in this way.[54]

Cooperative Education

Cooperative education or "co-op" — student work for academic credit and (usually) pay in industrial or corporate settings — is particularly important for engineers. It provides unique career enhancement integrated with academic training, with irreplaceable hands-on experience, improved access to modern equipment, role models, education, training, career guidance, testing, and screening. Earnings help pay college expenses, but financial aid is not the primary goal, and co-op is a less effective means of financial aid than work-study and other aid programs.[55] Engineering co-op graduates, like other co-op students, tend to receive higher salaries and better jobs. Yet

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54. Lionel V. Baldwin, "Tune In for Professional Development," *Engineering Education*, April/May 1987, p. 679.

55. James W. Wilson, Northeastern University, "Summary Report: Cooperative Education — A National Assessment," 1978, p. 22.

engineering co-op graduates are no less likely than other engineers to go on to graduate school.[56]

Engineering and technology have dominated cooperative education since the concept was implemented in 1906 by a civil engineer at the University of Cincinnati.[57] Much of the 1970s' growth in co-op programs, however, was in trade, business, and liberal arts.[58] Slightly over 36,000 engineering and engineering technology undergraduates (less than 10 percent of undergraduate enrollments) are in co-op programs.[59]

Engineering students have various sorts of work experiences. In one survey of young engineers, 16 percent had co-op experience, 44 percent had other engineering-related employment, 31 percent had nonengineering employment, and 8 percent had no undergraduate work experience at all.[60] However, Coop engineering students are much more likely than working nonco-op students to have work related to their majors.[61]

Federal support for co-op programs was first specifically authorized in 1968 amendments to the Vocational Education Act of 1963 and Title IV-D of the Higher Education Act of 1965 (HEA). The first significant appropriations under this legislation were not made until 1973, when $10 million was awarded by the Department of Education as seed grants for universities to start co-op programs. The number of co-op programs increased rapidly, and took another leap following further amendments in 1976, which placed co-op education in Title VIII of the HEA (see figure 4-10).[62] Impact was limited, as funds tended to seed many small programs. Regulation changes in 1979, designed to encourage expansion of programs, successfully increased enrollments.

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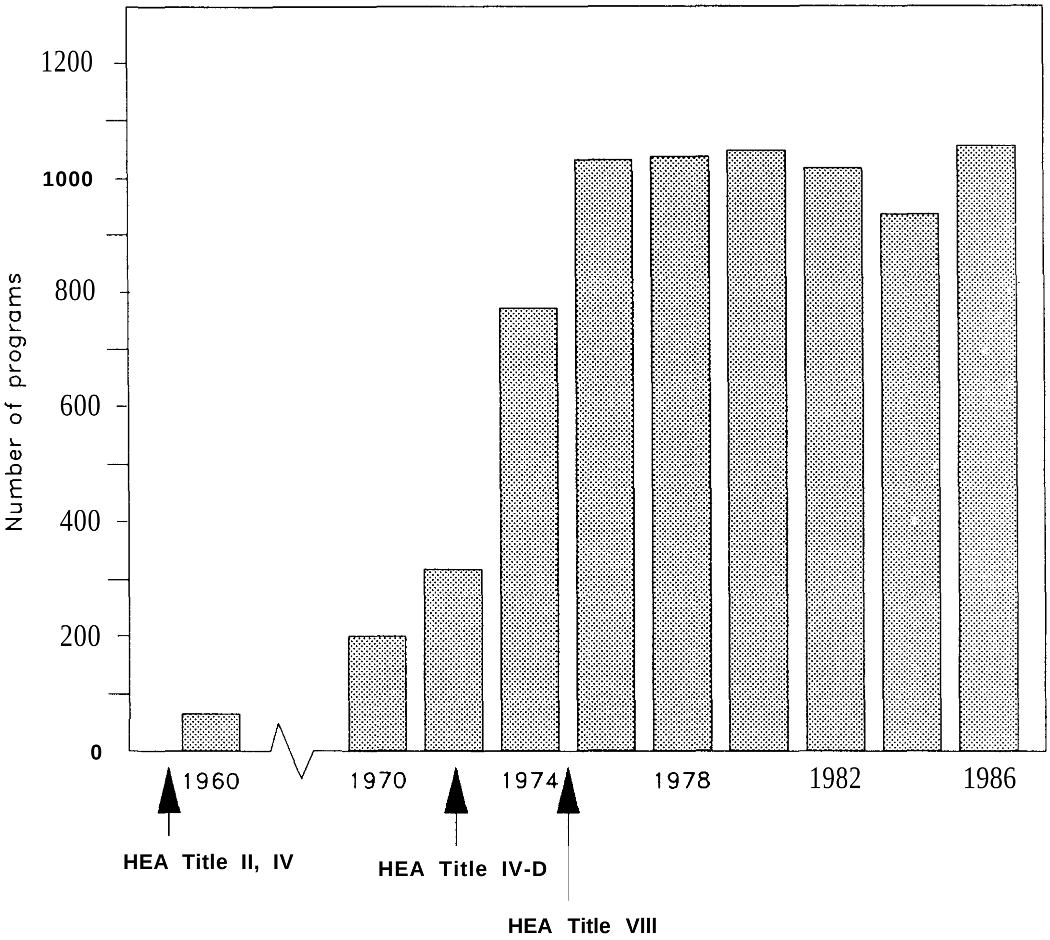
56. Sylvia J. Brown, *Cooperative Education and Career Development: A Comparative Study of Alumni* (Boston, MA: Northeastern University, Cooperative Education Research Center, 1976), pp. 36-38.
57. Richard P. Nielsen et al., *An Employer's Guide to Cooperative Education* (Boston, MA: National Commission on Cooperative Education, 1987), p. 1.
58. Wilson, op. cit., footnote 55, p. 46.
59. James W. Wilson, Cooperative Education Research Center, Northeastern University, "Cooperative Education in the United States and Canada," 1986, survey data.
60. Carolyn M. Jagacinski et al., "The Relationship Between Undergraduate Work Experience and Job Placement of Engineers," *Engineering Education,* January 1986, p. 233. The survey was limited to engineers who had graduated between 1961 and 1980 and who were working full time. They averaged 6 years since receipt of the baccalaureate.
61. Brown, op. cit., footnote 56, p. 36.
62. John Dromgoole et al., National Commission for Cooperative Education, "Change Management in Cooperative Education: The Expansion and Development of Title VIII Comprehensive Large Scale Co-op Programs," unpublished manuscript, n.d.

Figure 4-10. - Cooperative Education Programs, 1960-86



NOTES: Includes Canada (less than 5% of total programs).
In 1986, 1,016 U.S. programs enrolled 198,000 students.
Includes junior college programs, which account for about 40% of the total of both programs and students.
About 30% of cooperative education students are in engineering.

SOURCE: Cooperative Education Research Center, "Cooperative Education in the United States and Canada" (Boston, MA: Northeastern University, January 1987); and James W. Wilson, "Cooperative Education–A National Assessment" (Boston, MA: Cooperative Education Research Center, Northeastern University, April 1988).

State involvement in co-op programs has been small and sporadic. Foundations have also supported co-op education. The most important actors, the employers themselves, have generally not assumed a leadership role in coordinating the on- and off-campus experiences.[63] The Federal Government also has a lead role as an employer of co-op students, employing about 8,000.

UTILIZING AND UPGRADING THE ENGINEERING WORK FORCE

Continuing Education

Continuing engineering education is extensive and expanding.[64] Most engineers undertake continuing education during their careers; more that one-half of all engineers participate in some kind of training each year.[65] Concern about the supply of new engineers, rising costs, and improving corporate flexibility, industrial productivity, and efficiency has prompted investment and innovation in continuing education.

Continuing education is used to update specific technical skills. Companies invest more in formal continuing education and training for technicians than they do for Ph.D. engineers.[66] Young engineers are more likely than old ones to undertake such training. Although not strictly considered continuing education, extensive on-the-job training is usually required during the first year of engineering employment. It is not clear how much of this burden could be shifted to the universities or to joint university-industry programs. Much in-house training presumably is necessary to introduce new engineers to company equipment, procedures, and techniques.

Corporate needs have fostered many ad hoc arrangements with traditional educational institutions. In 1984, for example, General Motors (GM) contracted with 45

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63. National Research Council, "Engineering Education and Practice in the United States," *Engineering Undergraduate Education* (Washington, DC: National Academy Press, 1986), pp. 27-32.
64. Bruno O. Weinschel and Russel C. Jones, American Association of Engineering Societies, Toward *the More Effective Utilization of American Engineers,* (Washington, DC: American Association of Engineering Societies, 1986); Russel C. Jones and William K. LeBold, "Continuing Development to Enhance the Utilization of Engineers," *Engineering Education,* April/May 1986, pp. 669-673; and "Continuing Education," *Engineering Education,* April/May 1987, pp. 656-685.
65. National Research Council, *Engineering Education and Practice in the United States: Continuing Education of Engineers* (Washington, DC: National Academy Press, 1985), pp. 21-22.
66. Ibid., p. 22.

community colleges around the country for automotive technician training courses, with the college faculty receiving specialized training at GM.[67] Universities are offering more evening and short courses, televised and videotaped courses, and certificate programs. Industry contracts for technician training or continuing engineering education have become a significant revenue source for some engineering colleges and universities. The time and trouble of getting access to a desired course at a convenient time and place have prompted expansion of telecommunications-based distance continuing education, which allows employers to bring a specific course right into their offices or plant.[68]

Estimates of private investment in continuing education vary, but all indicate something on the order of tens of billions of dollars. Most is informal, on-the-job training — observing an experienced worker — but increasingly includes formal courses. Companies also pay about $10 billion annually in tuition for employees enrolled in conventional courses and degree programs.[69] The Federal Government also sponsors extensive retraining for both military and civilian technical employees.

These sums dwarf Federal education outlays. However, only large companies can afford extensive training. Corporate education expenditures correlate very strongly with R&D investment and ranking in the Fortune 500. Although society benefits, it is difficult for a company to recoup its investment when workers leave. Also, companies often reduce retraining support during business downturns, when retraining is most needed. Although many educational institutions are offering more continuing education, they often do not have the appropriate resources or faculty to do specialized mid-career engineering retraining in addition to their primary general teaching mission. Public

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67. Steven L. Goldman, "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, 1987. Also see David F. Noble, *America by Design: Science, Technology and the Rise of Corporate Capitalism* (New York, NY: Knopf, 1977).

68. Academic engineers can also benefit from continuing education; some argue that industry should play a larger role to keep engineering faculty abreast of industry advances and interests.

69. A number of reports, especially in the *Wall Street Journal*, and in conversations with executives at IBM, Hewlett-Packard, Motorola, Hughes, DuPont, and other medium to large companies, refer to the practice by more and more companies of reducing their engineering work force to a core group and hiring more contract engineers on a project-by-project basis (Pamela Atkinson, University of California, Berkeley, personal communication, November 1988). This will remind engineers of the virtues of entrepreneurship in marketing their talents. See National Academy of Engineering, *Focus on the Future: A National Action Plan for Career-Long Education for Engineers* (Washington, DC: 1988).

investment in retraining could be justified on the value of a well-trained work force to the economy, and helping individuals who may be dislocated or made obsolete by technological advance. Overcoming disincentives for retraining may require public policies to encourage company and industry-wide retraining, support retraining of government employees, increase individual investment in retraining (e.g., through tuition credits), and assist colleges, universities) and third party education providers in developing programs.[70]

Engineering Technicians and Technologists

Engineering technicians and technologists are vital support personnel in engineering practice and production. The vast majority of engineering technicians are employed in industry. There are over 1 million engineering technicians,[71] but their training and jobs are diverse and there is no well-accepted definition of technician or technologist. Electronics and electrical technicians are by far the largest category, accounting for over 40 percent of engineering technicians and technician-level degrees.[72] Major concerns are the supply of well-trained technicians, qualified at least at the 2-year associate level, and the capacity of institutions to train quality technicians.[73]

About 12,000 4-year bachelor's degrees and 14,000 2-year associate degrees were awarded in engineering technology in 1987 at programs surveyed by the Engineering

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70. U.S. Congress, Office of Technology Assessment, Technology *and the* Economic *Transition*, TET-283 (Washington, DC: U.S. Government Printing Office, 1988), pp. 240-251, 385; and Richard M. Cyert and David C. Mowery (eds.), *Technology and Employment: Innovation and Growth in the U.S. Economy* (Washington, DC: National Academy Press, 1987).

71. Betty M. Vetter and Eleanor L. Babco, *Professional Women and Minorities: A Manpower Data Resource* Service, 5th ed. (Washington, DC: Scientific Manpower Commission, August 1984), p. 198, table 7-31; and National Science Board, op. cit., footnote l,pp. 56-57, 221.

72. Estimates of the engineering technician population provided by Betty Vetter, Commission on Professionals in Science and Technology, based on Bureau of Labor Statistics data and the Engineering Manpower Commission's *Engineering and Technology Degrees* series. Vetter estimates 384,000 electrical/electronic technicians out of 984,000 total in 1985. The U.S. Departmentof Education's National Center for Statistics unpublished data on engineering technology/technician degrees are significantly higher than Engineering Manpower Commission data.

73. National Science Foundation, *Emerging Issues in Science and Technology, 1982*, NSF 83-61 (Washington, DC: 1983), pp. 49-58; 'Engineering Technology," Engineering Education, April/May 1987, pp. 724-755.

Manpower Commission.[74] Estimates of total associate level engineering degrees are on the order of 90,000 to 100,000.[75] Engineering technology programs have been growing rapidly; although there is some evidence of downturns in enrollments in the past few years.[76]

Technician and technology degrees are conferred by community colleges, 2- and 4-year city colleges, proprietary vocational-technical institutions, and to a lesser extent at State colleges and universities. Faculty tend to come from industry. In addition to formal degree programs, significant technician training and certification is done privately, through associations and companies. Most institutions are supported by tuition paid by students or employers.

Engineering technology and technician students and institutions have historically been outside the mainstream of U.S. science and engineering education, and beyond the reach of Federal engineering education programs. Though a source of engineering talent through mobility and training, they are often ignored in R&D policy. NSF, with its focus on universities, research, and Ph.D.s, has not been involved in technician training. Universities employ technicians, in science and engineering, but many of these are their own alumni. That situation is changing. The National Technicians Training Act, introduced (though not passed) in 1987, directed NSF to designate ten centers of excellence among community colleges to serve as clearinghouses and model training programs.[77]

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74. Richard A. Ellis, "Engineering and Engineering Technology Degrees, 1987," *Engineering Education*, May 1988, p. 792. The Engineering Manpower Commission collects partial data on 2- and 4-year accredited programs. These programs cover a majority, but by no means all, of formal 2- and 4-year programs. They do not cover certificate, pre-engineering, or less formal degree programs. Difficulties of definition of programs make data collection in this area very difficult.

75. These are 1984 data on associate degrees and other occupational curriculums greater than 1 year, but less than 4 years. U.S. Department of Education, National Center for Education Statistics, *Digest of Education Statistics* (Washington, DC: 1987), p. 216.

76. Richard A. Ellis, "Engineering and Engineering Technology Enrollments, 1987," *Engineering Education*, October 1988, pp. 51-54, reports declining enrollments through the 1980s; and in the May 1988 issue (Ellis, op. cit., footnote, 74) a downturn in 4-year degrees for 1987. Lack of good definitions, poor institutional recordkeeping, the diversity and informality of many programs, and changes in survey methods and scope make it difficult to track trends. Lawrence J. Wolf, "The Emerging Identity of Engineering Technology," *Engineering Education* April/May 1987 p. 725, reports, based on National Center for Education Statistics data, that engineering technology bachelor's degrees (and associate programs) have been growing about twice as fast as engineering degrees.

Technologist education may be even more equipment-intensive than engineering education. Hands-on experience is a hallmark of successful programs. Simulation and computer graphics can help. There is a chronic need for instructional materials, access to facilities, and employers' giving time off. Many large companies offer extensive in-housetraining, but have difficulty in hiring people to do the training.

Better coordination of course content and requirements between curricula at 2- and 4-year institutions could make it more likely that academically-oriented technician or technologist students would be able to transfer to engineering programs.[78] There is nothing in the American educational system comparable to the institutions created in England, France, and Germany in the 19th century to provide mobility into engineering jobs for skilled workers lacking formal education. The tension between the shop culture of early American engineering (dominant through the 1800s) and the university culture of science-based engineering (dominant after World War II) has widened the gulf between engineers with degrees and knowledgeable workers without them. Skilled workers possess valuable expertise, but without a formal credential or professional license they are not considered "engineers."[79]

Although technologists and technicians have degrees, engineering culture reinforces the status differential. Some argue that many engineers are employed in industry in capacities that do not use their formal training well, in jobs that could filled by other

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77. H.R. 2134, *Congressional* Record, vol. 133, No.62, Apr. 22, 1987.

78. An underlying issue is the content of the college-preparatory 'academic" curriculum track in high school as opposed to the 'vocational' track:

> One of the most important and least understood segments of the education and training system is the set of institutions that provide vocational training. . . . The proportion of postsecondary students enrolled in vocational fields has increased notably, as have the number and variety of service providers. Yet little is known about the institutions and people that constitute the system of postsecondary vocational education, the reasons students enter and exit the system and, ultimately, the extent to which students benefit from the training they receive.

National Assessment of Vocational Education, *First Interim Report* (Washington, DC: January 1988), p. 6-1. Under the Perkins Vocational Education Act, high school vocational education serves a diverse clientele. Programs under the Comprehensive Employment and Training Act and Job Training Partnership Act are for different purposes and have not directly addressed the need for technicians. Warren Anderson, 'Community Colleges and Technician Training," testimony before the House Subcommittee on Science, Research and Technology, Committee on Science and Technology Committee, Sept. 30, 1985, p. 231.

79. See, for example, National Societyof Professional Engineers, "PE — A License for Success," Engineering *Times, vol.* 8, No. 3, May 1986, p. 4.

expert workers. The situation suggests that technicians and technologists could augment the ranks of engineers in times of high demand.[80]

ROLES OF THE FEDERAL GOVERNMENT

Industry dominates the engineering labor market. Universities generate the supply of new engineers. Together with the professional engineering community, industry, and academia have shaped engineering education. The Federal Government, although a major player, affects engineering education mainly indirectly, by supporting higher education and academic research, and by mounting major national R&D programs that drive industrial and academic demand for engineers. Federal R&D and student support programs can affect the distribution of engineers among fields and sectors, but most of this fine-tuning is overshadowed and overtaken by the effects of the labor market. The Federal Government has left most supply adjustments to the market.

This approach has worked fairly well, but periodic shortages of engineers bring calls for Federal "remedies," such as to produce more engineers in the specialties in vogue and to provide timely information on engineering labor markets. The rising cost of engineering research and education has drawn attention to Federal funding for university equipment, facilities, and institutional development. Federal actions have also been prompted by social concerns, such as access of minorities and women to engineering careers, and having sufficient personnel to work on high-priority Federal military, space, and public works R&D. Federal concern for a healthy supply of engineers has been boosted by the historically increasing Federal role in business and R&D, and pressure for coordinated national action to stimulate innovation and international industrial competitiveness.

About 8 percent of engineers work directly for the Federal Government or military, but far more engineering employment depends directly or indirectly on Federal R&D and procurement (largely defense-related).[81] Roughly 20 to 40 percent of engineers are employed in defense-supported work, most in industry and government.[82] On campus,

80. This is why industry has adamantly not supported the hiring of only engineers with a P.E., and why continuing education for relicensure has never gained momentum. Industry can hire anyone it wants and call him or her an 'engineer.'

81. National Science Foundation, U.S. Scientists *anal Engineers:* ***1986,*** NSF 87-322 (Washington, DC: U.S. Government Printing Office, 1988), p.36.

82. Ibid., p. 118, 124; and Michael Davey and Genevieve Knezo, Congressional Research Service, 1987, "The Federal Contribution to Basic Research: Background Material for

military spending is a substantial amount of the support received by engineers: DoD is the source of research funds for one-quarter of academic engineers.[83] The rising DoD presence in Federal R&D spending worries some that the military will siphon engineers from industry and widen the gap between military and civilian skills. One recent report concluded, however, that military R&D spending increased demand for engineers, which in turn bolstered the supply and benefited all employers of engineers — civilian, academic, and military.[84]

Graduate Education

There have been continuing shortages of Ph.D. engineers. A recent survey of engineering department heads reinforced the role of financial assistance in attracting graduate students (again see table 3-12 in the preceding chapter).[85]

Doctoral engineering programs grew rapidly after World War II, with the encouragement of the G.I. Bill, the National Defense Education Act, and large Federal research expenditures. Engineering Ph.D. awards rose from about 100 annually in the early 1940s to about 3,700 in the mid-1970s. The subsequent decline can be attributed to various factors: the end of the military draft, a ratcheting down of demand for engineering doctorates in industry and continuing strong employment of engineering baccalaureates, modest growth in academic hiring, and the waning attractiveness of academic posts when research money is tight (compared to the 1960s and 1970s) and teaching demands high (due to high undergraduate enrollments).

The early-1980s boom in undergraduate enrollments could swell the graduate population, but there is no sign of this yet and in the past there has not been a direct relationship between engineering B.S. awards and graduate enrollments. Some have predicted an increase in Ph.D. production approaching 4,000 Ph.D.s per year.[86] To

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83. The Department of Energy supports 17 percent, much of that defense-related; the National Aeronautics and Space Administration and the National Science Foundation support 14 percent each. National Science Foundation, op. cit., footnote 81, p. 129.

84. National Academy of Engineering, *The Impact of Defense Spending on Nondefense Engineering Labor Markets* (Washington, DC: National Academy Press, 1986), esp. Eli Ginzberg, "Scientific and Engineering Personnel: Lessons and Policy Directions," pp. 25-41.

85. Faculty attitudes toward undergraduate engineering students is a "wild card": abundant anecdotes indicate that encouragement, along with increased graduate stipends, would make a difference. The College of Engineering at the University-of Illinois-Urbana is a case in point.

86. National Research Council, *Engineering Graduate Education and Research*

achieve this, incentives for graduate study, and especially the redoubling of efforts to inform students about engineering opportunities, will have to improve (for an example, see box 4-E).

The Federal Government is the primary source of support in graduate school for less than 10 percent of U.S. engineers who earn Ph.D.s, and less than 5 percent of all Ph.D. engineers (see table 4-3).[87] Research assistantships are the most widespread funding source; they support nearly three-quarters of successful Ph.D.s and are primary support for over one-half of Ph.D.s. Loans supplement other funds for few students. Ph.D. engineers are twice as likely as Ph.D. scientists to have received support from industry or an employer (8 percent v. 4 percent in 1986), but industry's role is still quite small relative to university and Federal support.[88] A comparison of sources and types of support awarded to engineering and science graduate students in 1986 is presented in table 4-4.

From 1973 to 1983, graduate stipends fell from one-half to nearly one-quarter of rapidly rising starting salaries for B.S. engineers.[89] To lure engineering students away from high-paying industry jobs and into graduate school, many institutions have increased the amount of graduate student stipends, based on a rule of thumb of one-half of industry starting salaries (which approach $30,000 for B.S. engineers). The creation of industry-linked academic centers for engineering research (for example, NSF-supported Engineering Research Centers and the many anticipated local variations on them[90]) could enhance the attractiveness of academic careers more than simply increasing graduate stipends. More likely, academic centers will be a phase; like so many other proposed innovations, it will fade as a fashion or be absorbed into the academic culture of engineering.

Federally and State sponsored interdisciplinary engineering research centers and new university-industry institutions, such as the Engineering Research Centers, have been geared not only to R&D but also to education and manpower development.

(Washington, DC: 1985), p. 1.

87. The proportion of graduate students with Federal support, as opposed to those who complete Ph.D.s, is 2 to 3 times higher.

88. National Research Council, op. cit., footnote 36, p.54.

89. Jerrier A. Haddad, "Key Issues in U.S. Engineering Education," *The Bridge*, summer 1983, p. 12.

90. Nam P. Suh, "The ERCs: What We Have Learned," *Engineering Education*, vol. 78, No. l, October 1987, pp. 16-18.

Table 4-3. — Primary Source of Support, 1986 Engineering Ph.D.s
(in percent)

Source of Support	Engineering Sciences N=2,754[a]	Computer Sciences N=340[a]	All N=13,654[a]
Institutional[b]	68	58	54
Federal	6	4	11
Personal	16	26	30
Other[c]	10	12	6

[a]Number reporting source of support, about 90 percent of total Ph.D.s.
[b]Includes State.
[c]Includes corporate and foreign.

SOURCE: National Research Council, unpublished 1987 data.

Table 4-4. — Primary Sources and Types of Support of Engineering and Science Graduate Students, 1986 (in percent)

Type of primary support	Engineering	Science
Fellowship	8	9
Federal	1	2
Non-Federal	7	7
Traineeship	1	7
Federal		4
Non-Federal	1	2
Research assistantship	34	23
Federal	16	12
Non-Federal	18	11
Teaching assistantship	18	25
Federal		
Non-Federal	18	25
Other	38	37
Federal	3	3
Non-Federal	35	35
Primary source of support		
Federal	21	19
Department of Defense	7	2
National Science Foundation	5	4
Other Federal	9	13
Institutional	33	44
Other	17	8
U.S.	13	6
Foreign	4	2
Self-support	29	29

NOTE: Full-time students in doctorate-granting institutions. Students in master's-granting institutions have a similar distribution of support: slightly more self-support, less Federal, and slightly less research assistantship support.

SOURCE: National Science Foundation, Academic Science/Engineering: Graduate *Enrollment and Support, Fall 1986,* NSF 88-307 (Washington, DC: 1988), pp. 49-50, 153-167.

Education goals are to bring students into contact with industry personnel and R&D problems and, in some cases, develop new engineering curricula.[91] Little is known as yet of the impacts of such centers on education, in part because NSF eschewed evaluation efforts from the start. Congress continues to monitor the educational activities of industry-university centers.[92]

About 150 universities offer engineering Ph.D.s.; many award only a few each year. Thirty institutions produce nearly two-thirds of engineering Ph.D.s. These same institutions receive a large share of Federal R&D funds. The National Research Council concluded that the existing institutions could expand production significantly without creating new Ph.D. programs, and that building on the existing base of faculty, equipment, and facilities would be most cost-effective.[93]

The engineering doctorate mixes two philosophies. Industry still dominates employment of Ph.D.s, but the research-oriented science model guides engineering graduate study — inappropriately, some claim.[94] The deterioration of U.S. competitiveness has called into question the value to industry of this academic model, entrenched during the 1960s' explosive growth of Federal research funding, graduate student support, and doctoral enrollments. Many engineering faculty who earned doctorates during the 1960s and 1970s, so the argument goes, have lacked appreciation for the relation of engineering to industrial production. This faculty bias is said to promote a neglect of design in undergraduate engineering coursework and a failure to relate engineering solutions to the creation of manufacturable and marketable products. Given the strong symbiosis between engineering education and industry, this issue is now receiving renewed attention.[95]

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91. Edmund T. Cranch, Department of Defense and Carnegie-Mellonts Software Engineering Institute, "Continuing Education in the United States," *Engineering Education,* April/May 1987, p. 663.
92. See U.S. Congress, General Accounting Office, *Engineering Research Centers: NSF Program Management and Industry Sponsorship,* GAO/RCED-88-177 (Washington, DC: 1988).
93. National Research Council, op. cit., footnote 86, p. 85.
94. See Edwin T. Layton, "Science as a Form of Action: The Role of the Engineering Sciences," Technology *and Culture,* vol. 29, January 1988, pp. 82-103.
95. American Society for Engineering Education, A *National Action Agenda for Engineering Education* (Washington, DC: 1987), pp. 15-17. Also see National Research Council, *Engineering Personnel Data Needs for the 1990s* (Washington, DC: National Academy Press, 1988).

For example, poor management of manufacturing has been offered as the reason for the United States failure to take commercial advantage of home-grown technological developments. Ignoring manufacturing and relegation of manufacturing technology to technical schools is seen as catastrophic not only for mechanical engineering, but also for American manufacturing in general.[96] Compared to other engineering specialists, manufacturing engineers earn the lowest median income. Only a handful of U.S. institutions grant degrees in manufacturing engineering or systems. If the definition is broadened to include programs in computer-aided manufacturing, automation, materials, processes, robotics, and production, one-fifth of the 221 institutions listed in the ASEE 1986 Directory of Engineering College Research *and* Graduate Study qualify. This measure, while crude, suggests the lack of emphasis placed on manufacturing by U.S. universities and engineering institutes.[97] As one antidote, the National Institute of Standards and Technology is establishing technology centers at three eastern colleges, two (at Rensselaer Polytechnic Institute and Cleveland's Cuyahoga Community College) will be devoted expressly to manufacturing technology.[98]

CONCLUSION

The view persists that the future supply of engineers is directly related to technological innovation and the competitiveness of industrial production. Technology studies scholars, however, generally agree that managerial decisionmaking dominates the innovation process and that competitiveness is determined by a wide range of corporate, political, and social policy decisions that distance innovation and competitiveness from engineering education.[99] The engineering curriculum will continue to reflect the tension between longer-term academic priorities and shorter-term industrial needs. While there is no consensus on the "best" engineering curriculum, salutary features include communication between university and industry, work experience, hands-on laboratory

96. National Academy of Engineering, *Education for the Manufacturing World of the Future* (Washington, DC: National Academy Press, 1985); and Reuel Shinnar, "The Crisis in Chemical Engineering," *The Bent of Tau Beta Pi*, fall 1987, p. 20.
97. W.J. Fabrycky et al., "Engineering College Research & Graduate Study: A 20-Year Statistical Analysis," *Engineering Education*, vol. *76, No. 6,* March 1986, pp. 326-340.
98. See Will Lepkowski, "NIST Launches Technology Centers," *Chemical and Engineering News*, Jan. 9, 1989, p. 26.
99. Goldman, op. cit., footnote 67. For a bilateral dialogue on approaches to engineering education, see Edward E. David and Takahi Mukaibo, *Engineering Education: United States and Japan*, Proceedings of the Fourth U.S.-Japan Science Policy Seminar, Oct. 19-23, 1986, Honolulu, Hawaii (Washington, DC: National Science Foundation, 1988).

experience, and ongoing scrutiny by the academic and professional engineering communities.[100] Engineering education will not "save" the Nation or restore its economic vibrancy; it can, however, give a competitive edge to America's technology base.

100. Joseph Bordogna et al., "Linking Management and Technology — A Decade's Experience," Engineering *Education,* vol. *78,* October 1987, pp. 23-28. Also see 'dward Wenk, Jr., "Portents for Reform in Engineering Curricula," Engineering *Education,* '01* 78, November 1988, pp. 99-102; and Hans Mark and Larry Carver, "Educating Engineers for Leadership: The Fourth Revolution," *Engineering Education,* vol. *78,* November 1988, pp. 104-108.

Box 4-A. — Perennial **Issues in Engineering Education**

Many engineering education issues center around the often conflicting priorities of academia, industry, and government as employers of engineers.[1] These conflicts are by nature irreconcilable, so that engineering education is likely to be a continuing arena of debate and its curriculum a continuing compromise between its many clients.

Current calls for reform of engineering education are only the latest among many from a community that has been extraordinarily self-conscious about its responsibility to students and its contributions to the economic vitality of the Nation. Since 1985 alone, the engineering community has called attention to the tension between education and practice, the measurement of quality, the National Science Foundation's Engineering Research Centers, and the impact of foreign graduate students on engineering education and employment.[2]

The roots of these concerns run deep. An OTA review of all major reports on engineering education, from the 19th-century birth of the profession through 1987, revealed a number of themes and perennial controversies that have defied easy resolution:[3]

- **Curriculum**
  The extent to which the undergraduate engineering curriculum should provide a general education or employment-guided training, and the extent to which industry's short-term needs should shape engineering education.

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1. Robert Perrucci and Joel E. Gerstl, Profession *Without Community* (New York, NY: Random House, 1969); Edwin Layton, Jr., *The Revolt of the* Engineers: *Social Responsibility and the American Engineering Profession* (Baltimore, MD: The Johns Hopkins University Press, 1969); David F. Noble, *America* by *Design: Science, Technology and the Rise of Corporate Capitalism* (New York, NY: Knopf, 1985); and Lawrence P. Grayson, "A Brief History of Engineering Education in the United States," *Journal of Engineering Education,* December 1977, pp. 246-264.
2. W. Edward Lear, *The Quality of Engineering Education Programs* (Washington, DC: American Society for Engineering Education, 1986); Don E. Kash, The *Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987); and Elinor G. Barber and Robert P. Morgan, "The Impact of Foreign Graduate Students on Engineering Education," *Science,* vol. *236,* Apr. 13, 1987, pp. 33-37.
3. Steven L. Goldman, "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, 1987.

Distinguishing between engineering practice and science, and balancing the curriculum a) between more "theoretical" courses in mathematics and physical science and "practical" engineering courses, and b) between generic engineering science courses and specialized courses.

- **Faculty**
  The appropriate qualifications for engineering faculty in the “real world” practice of engineering, and the extent to which industry experience, in addition to a university Ph. D., is a desirable and sufficient credential for a faculty post.

- **Credentials**
  A 4-year v. a 5-year “undergraduate” program. The difficulty of preparing for a career and responding to a large and rapidly changing knowledge base in a 4-year B.S. program raises the issue of adding at least 1 more year, making the a 5-year B.S. or M.S. the first professional degree in engineering. However, 4-year programs are attractive to students, who can move into high-paying jobs, encouraged by a volatile, technology-responsive labor market.

  The proper role of government licensing and certification by an engineering professional society, in addition to job performance, as determining membership in the professional engineering community.

  The proper role and education of technicians, technologists, and paraprofessional engineers.

- **Careers and Continuing Education**
  Encouraging continuing education and professional development for engineers, including engineering faculty, and balancing this with the preference of some employers to invest in cheaper, younger, fresher engineers.

Engineering and Society

Balancing engineers' responsibilities to employers, and building into engineering practice explicit recognition of the social impacts of technological innovation and the value-laden character of engineering judgment.

Box 4-B. — Expanding the Engineering Pool: Recommendations of the Engineering Deans Council

To attract more able students, to provide a more supportive environment, and to make engineering education more accessible, engineering educators should:[1]

Improve undergraduate recruitment and retention, especially of women and minorities

- Support and publicize intervention programs tailored for women and minorities through institutional consortia.
- Improve guidance materials.
- Strengthen elementary and secondary mathematics and science education.
- Coordinate curricula and counseling with community colleges to increase transfer to 4-year colleges, especially for women and minorities.
- Encourage dual-degree and transfer programs with liberal arts colleges.
- Keep better data on educational and career paths, especially retention rates.
- Implement lessons from successful intervention programs which improve the academic performance and retention of engineering undergraduates, especially women and minorities. In particular, support:
  - extended programs which allow students to proceed at a slower pace;
  - ambience that encourages nurturing, not weeding out;
  - orientation and transition programs for entering freshmen;
  - engineering student organizations; and
  - effective academic advising.
- Ensure that faculty are sensitive to the special needs of women and minorities.
- Establish specific goals, such as doubling the number of women enrolled by the end of the decade.

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1. Based on Report of the Task Force on the Engineering Student Pipeline, “Findings & Recoin mendations," *Engineering Education, vol.* **78,** May 1988, pp. 778-780.

- Support programs to help women re-enter engineering after career interruptions.

Increase graduate enrollments

- Establish recruitment and retention goals for minority students.
- Sharpen recruiting of U.S. engineering graduate students, by:
  - actively targeting and recruiting promising undergraduates;
  - encouraging undergraduates to do research;
  - developing ties between graduate schools and undergraduate institutions with large minority enrollments;
  - opening engineering graduate study to nonengineering undergraduates;
  - publishing a guide to graduate programs; and
  - creating a listing in which graduate students and schools can find each other.
- Adjust graduate student stipends to at least one-half the starting salary for a B.S. engineer.
- Double the number of graduate fellowships available.
- Restore the tax deductibility of both tuition remission and graduate student stipends.

Box Box 4-C. — The Minority Introduction to Engineering Program (MITE)

The MITE program encourages high school students to enter and stay in engineering. MITE students gain confidence in science and engineering, are more likely to change their high school curriculum to prepare for college and technical majors, and are more likely to enter and stay in science and engineering majors in college than their peers.[1] Funding for MITE, like most other such programs, comes Primarily from large corporations and corporate foundations.

MITE students are exposed to a college environment and "real” engineering in summer university-based programs. Each summer about 1,000 to 3,000 MITE students spend 1 to 8 weeks in programs at various engineering institutions. The typical program is 2 weeks, the typical student a Black male between junior and senior year in high school. The students tend to be high achievers, college-and engineering-oriented, and from a privileged socioeconomic and education background. Program content varies widely, as does the makeup of student groups.

Student alumni report favorable changes in high school courses, plans for college (70 to 80 percent apply) and planned major (70 to 90 percent engineering), impressions of the MITE program, and the impact of the program on their college and field decisions. MITE participants have a much lower first-year attrition rate than other minority engineering students.

Several 5-year followups all bear positive news on college attendance, major, jobs, post-graduation plans, financial aid, and the impact of the MITE program.[2] Almost all ex-MITE students are in college, most are in science or engineering majors, and many plan graduate study. Women especially are encouraged by participation in MITE. About one-half of the students attend the college where they did their MITE program.

1. MITE began in 1974. Since 1975 MITE has conducted evaluations, based on annual and 5-year followup surveys. Survey results are incomplete and nonrepresentative. UNITE, a separate military extension of MITE, is not included in this discussion. Both are creations of JETS, the Junior Engineering Technical Society.
2. Conducted by the Accreditation Board for Engineering and Technology. Response rates have been 15-20 percent.

MITE is drawing on students who are already interested in engineering in college. Three-quarters of the students going into MITE already prefer engineering; 80 percent coming out do.

Box 4-D. — The National Technological University

The National Technological University (NTU), based in Fort Collins, Colorado, offers specially developed science and engineering courses by satellite communications to technical staff at corporate and educational centers. Technical professionals can thus keep their skills up-to-date without the disruption and expense of leaves of absence. Twenty-eight universities and 60 sponsoring corporations and government agencies nominate students for NTU coursework.[1]

NTU encourages its sponsors to create courses, spreading the very considerable cost of development over a much larger base than that available to any single institution. The amortized cost of development, distribution, and electronic distribution allows a great variety of specialized courses to be developed and offered on very flexible schedules.[2]

In general, corporate education programs reflect greater educational efficiency than schools and colleges. They spend far more time and money on evaluating and experimenting with different teaching and learning formats. They are, therefore, a potentially valuable resource for colleges implementing educational technologies and techniques about which industry may already have accumulated great deal of data. The Federal Government, a subscriber to NTU, also supports research and experimentation.

NTU is not the only one of its kind, although it is by far the largest and has absorbed many smaller systems. One-way education video, with audio teleconferencing, expanded from a single system in 1964 to over 40 systems in 1986, serving over 50,000 engineers and other technical professionals. The phrase, the "televersity," has been

1. James Krieger, "Management-of -Technology Program Debuts," *Chemical & Engineering News,* Jan. 16, 1989, p. 34. Six M.S. programs are now offered: computer engineering, computer science, electrical engineering, engineering management, manufacturing systems engineering, and the newest offering in management of technology.

2. Most National Technological University (NTU) courses originate in member universities, and a few in industry. There were about 120 sites in the fall of 1987; two channels broadcast 18 hours a day. In 1987 NTU offered 120 courses, with 4,000 hours of graduate credit instruction. This remote learning seems to be as effective as traditional classroom instruction. *NTU News,* vol. *3, No. 4,* November 1987.

applied to the NTU phenomenon.[3] General trends driving greater use of televised, computerized, and distance education are:

- the high and rising proportion of students who are employed and studying part time;
- technical improvements;
- cost decreases and economies of scale as more users get on the systems;
- the high cost of release time and commuting time for employees to take courses in traditional classrooms;
- the higher demand for continuing technical education to maintain work force competence and improve productivity;
- employee and union interest in continuing education; pressure for education as employee benefits; worker satisfaction;
- market pressure on universities to find new sources of revenue and new services to provide; and
- the rise of non-university educational providers.

3. Thomas L. Martin, Jr., *The Televersity: The University of the Future* (Surrey, England: Industry and Higher Education, September 1987).

Box 4-E. — National Consortium for Graduate Degrees for Minorities in Engineering, Inc. (GEM)

GEM sponsors about 100 to 160 students a year in master's and doctorate engineering study. Since GEM's founding in 1976, 12 percent of minorities holding graduate engineering degrees have been sponsored by GEM.[1]

The director of the program, Howard G. Adams, cites the heavy recruiting and high salaries offered by industry as a major reason that minorities do not go on for graduate engineering education. Other reasons include the perception that an advanced engineering degree is worth little in terms of career or salary, ignorance of the availability and process of financing graduate study, and competition from other majors such as business and law.[2] In addition, students face institutional barriers, GRE scores, poor academic preparation. Adams offers four recommendations for institutions:[3]

- intensify efforts to identify and recruit full-time minority graduate students with undergraduate research assistantships, open houses and career days, participation by minority faculty and students (especially in recruitment at minority colleges), and publicity materials that target minorities;
- revise criteria for admissions by considering qualitative information such as motivation and work experience, explain how admissions works, and make sure that admissions criteria are appropriate for student success;
- provide financial support, ensure its equitable distribution, and use teaching and research assistantships to foster faculty-student interaction; and
- make sure the academic environment involves and supports minorities in teaching and research apprenticeships, seminars, publishing and " presentations, and advising.

1. *Manpower Comments,* vol. 25, No. 3, April 1988, p. 17.
2. Howard G. Adams, "Advanced Degrees for Minority Students in Engineering," *Engineering Education,* vol. 78, May 1988, pp. 775-777.
3. Ibid., p. 777.