Chapter 1

Diversity of Students and Institutions

Chapter 1
Diversity of Students and Institutions

American colleges and universities prepare undergraduate and graduate students to become the next generation of scientists and engineers. These institutions immense influence on students' careers, skills, and attitudes determines the size, composition, and quality of the future science and engineering work force. To effect any significant change in this work force will take long-term public policy efforts at all levels of education, and commitment by families, businesses, and communities. Colleges rely on elementary and secondary schools; yet without sufficient academic preparation (particularly in mathematics) and interest in science, children will not be able to succeed in a college major in science or engineering.[1]

Large research universities, small liberal arts colleges, the historically Black institutions, 2-year institutions, and a mix of special-purpose colleges, universities, and technical institutes, public and private, make American higher education highly diverse in size, purpose, and structure. Each type of institution provides a unique environment for developing ability and encouraging persistence. No one environment is suitable for all students (although some institutions produce more scientists and engineers than others). This report looks at these institutions as producers of a future work force, and provides a perspective on fledging scientists and engineers.

STUDENTS AND HIGHER EDUCATION

The quality and diversity of American higher education in all fields is globally respected. Enrollments continue to grow, but demographic trends portend a decline in the number of college-age students in the 1990s, with some increases early in the 21st century. Since demand for scientists and engineers is expected to increase, many policy makers worry that the supply of new graduates will fall significantly short.

---

1. 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). While action at the elementary and secondary level will not affect the supply of entry-level and Ph.D. scientists and engineers in the next few years, long-term improvement and expansion of the pool of scientists and engineers must be built on the base of a well-prepared, enthusiastic population of high school graduates.

Universities warn that their aging instructional equipment and facilities hamper their ability to deliver a quality technical education. In addition, as demand for workers in emerging fields outstrips the availability of new graduates, there are continuing mismatches between supply and demand in specialized fields, as well as continuing vexation over the low representation of women and minorities in science and engineering professions.

A strategy to increase the supply and quality of young scientists and engineers must be based on an understanding of the unique problems fostered by demographic change. Such strategies should include recruiting more students into science and engineering majors, particularly the undertapped resources of women and minorities; retaining more of these through higher degrees and into technical careers; and bolstering the college and university infrastructure for instruction and research. Special programs that prepare students, provide them with academic and social support, and involve them in hands-on research, help keep students in science.

A robust job market reflects a robust economy, which, in turn, powers Federal and national research and development (R&D) spending and boosts student recruitment and retention.[2] Undergraduate financial aid has created a substantial pool of college students from which science and engineering, among other fields, have drawn talent. institutions of higher education can do more, as reflected in the many initiatives of individual colleges and universities, as well as in programs sponsored by industry and professional societies.[3]

Many students come to science and engineering during college, not before. A national study showed that 20 percent of science/engineering majors had not planned science or engineering majors during high school. More might enter if they were not stymied by the relative rigidity of most science and engineering curricula, which demand early commitment to a sequence of courses, particularly in mathematics.[4] The

---

2. For an elaboration on these and the policy options summarized below, see U.S. Congress, Office of Technology Assessment, Educating *Scientists and Engineers: Grade School to Grad School, OTA-SET-377* (Washington, DC: U.S. Government Printing Office, June 1988), esp. ch. 4.

3. For example, see Elaine El-Khawas, *Campus Trends, 1988,* Higher Education Panel Report Number 77 (Washington, DC: American Council on Education, September 1988).

4. Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, 1987. Based on the High School & Beyond survey, following high school sophomores of 1980 through their college sophomore year (1984). Many of the findings reported here derive from analyses

flexibility of student interest indicates that science and engineering programs could seek out students as late as their sophomore or even junior years of college, and that colleges could help by providing administrative and curricular gateways for students to change majors and "catch up."

At the graduate level, putting money into U.S. research universities — through research grants, research and teaching assistantships, fellowships, and traineeships — has proved a relatively straightforward mechanism for increasing the supply of quality Ph.D.s. Targeted financial aid, mostly research training subsidies for graduate students, enables students interested in research careers to pursue the lengthy training required, and may even attract more students. Upgrading the capacity for graduate education is a costly and long-term endeavor; even large, elite institutions require continuing support to maintain the quality of their research and education programs.[5]

Unlike elementary and secondary schooling, higher education in the sciences and engineering is subject to direct Federal influence. About 13 percent of the $60 billion dollars spent annually by all levels of government on higher education comes from the Federal Government. Federal funding is particularly important at the graduate level, where Federal fellowships and other forms of assistance are awarded to support specific graduate students in specific fields of study, and where the majority of academic research is supported by Federal funds. Federal R&D programs are also highly influential in graduate education since they provide employment opportunities for researchers in universities, industry, and government, and thus heighten the attraction of graduate research training.

ORGANIZATION OF THIS REPORT

This report is presented in three chapters: undergraduate, graduate, and engineering education. This reflects divisions both in the organization of the higher education enterprise and in the policy actions relevant to each.[6]

---

performed in 1987 as part of the assessment that led to Office of Technology Assessment, op. cit., footnote 2. In some cases, databases have been updated; for most of OTA% results, the terminal data point is 1986, though some enrollment and degree data extend to 1987.

5. Arthur M. Hauptman, "Higher Education May Face an Era of Retrenchment No Matter Which Candidate Is Elected in November," *The Chronicle of Higher Education*, Oct. 19, 1988, p. A52.

6. This report was neither conceived nor written as a policy document. It contains no

Undergraduate education has traditionally been characterized by diversity, with several thousand colleges and universities pursuing very different missions and student bodies. The Federal role has been one of providing financial support to ensure individuals educational opportunity; a concern for equity has set the policy tone.[7] Federal science-related programs for undergraduate research, faculty, and institutions have been limited in extent but potent in effect. That is, specific fields have seldom been singled out for Federal support.

Graduate education has long been an area of direct Federal action, because of the national need for Ph.D.-trained scientists and engineers. Extensive Federal subsidies of graduate education and university research have strongly shaped the nature and extent of graduate education, and the supply of science and engineering Ph.D.s.[8]

Educating engineers differs from educating research- and academically-oriented scientists; the vast majority of engineers work in industry, and can seek a relatively high-paying professional job with a bachelor% or master% degree rather than a Ph.D. (A strong baccalaureate market exists for physicists, chemists, and computer scientists as well, so the similarities between the entry-level destinations of some scientists and engineers belies the general differences in their undergraduate preparation.) The national attention to manufacturing and technological competitiveness augurs an increasing Federal interest in the quality of engineering education.

Undergraduate Education

The Federal Government has been instrumental in expanding access to college. Financial aid in all forms, including the G.I. Bill, has helped many low- and middle-

---

single policy section or chapter. Rather, it is an education research report with a devotion to data and an eye on what they might mean for the members of various communities, including policy makers. For a recent example of a similar document written from an academic perspective, see Richard J. Shavelson, "Contributions of Educational Research to Policy and Practice: Constructing, Challenging, Changing Cognition," Educational Researcher, vol. 17, October 1988, pp. 4-11, 22.

7. Kathryn Mohrman, "Unintended Consequences of Federal Student Aid Policies," *The Brookings Review*, vol. 5, No. 4, fall 1987, pp. 24-30.

8. For a review of Federal legislation in fiscal years 1988 and 1989 geared to science and engineering education, see U.S. Congress, Congressional Research Service, *Major Legislation of the Congress*, Issue No. 3 (Washington, DC: U.S. Government Printing Office, August 1988), pp. MLC-021, MLC-102; and U.S. Congress, Congressional Research Service, "Education: The Challenges," *Congressional Research Service Review*, vol. 9, No. 9, October 1988.

income students attend and complete colleges; scholarships have been particularly effective. Science and engineering undergraduates are similar to other students in their use of aid, and loan burdens do not seem to affect students' choice of major or decision to attend graduate school. The vast majority of aid has been given solely on the basis of need, without regard to the interests of the students or the institution they are going to attend. Educators have suggested creating a scholarship (based on merit and/or need) for undergraduates majoring in areas of national need, such as science and engineering. Although this diverges from conventional policy wisdom, there is precedent in special scholarships for future teachers. Such a program would likely encourage some students to pursue targeted fields, although the extent and effect of such a program is uncertain.

The abundance of college-educated students has benefited all professions, including science and engineering. The level of college enrollments is important to the supply of scientists and engineers, who have in the aggregate maintained for more than 3 decades a fairly steady 30 percent share of all baccalaureates (20 percent for natural science and engineering). However, there have been significant shifts in the distribution of students among fields within science and engineering, reflecting undergraduates' changing interests as well as the job market. The social sciences, and to a lesser extent the physical and biological sciences, have experienced steady declines, while engineering and computer science have been rising in popularity (until very recently). Science and engineering majors continue to attract a high proportion of academically able students.[9]

Another perspective on the future supply of scientists and engineers centers on the phenomenon of attrition. Fewer than half of freshman science and engineering majors complete a baccalaureate in science and engineering. However, some peer and academic support programs have been effective in helping students complete their chosen majors. Such programs are being widely publicized, expanded, and replicated.[10] In the long run, however, efforts to reduce attrition or attract new talent will collapse unless students perceive career opportunities in research, teaching, and practice. Unless job markets are strong, increasing the output of scientists and engineers will result only in underemployment and frustration. Strong job markets in academic research and teaching, as well as Federal, State, and industrial R&D initiatives, can elevate

---

9. Kenneth C. Green, University of California, Los Angeles, personal communication, 1987.

10* Edward B. Fiske, "Accountability Looms as the Watchword of the 90s in Higher Education," *New York Times Education, Nov.* 16, 1988, p. B8.

enrollments, although spot shortages and surpluses at disciplinary and subdisciplinary levels are to be expected in a dynamic economy.

The quality of undergraduate education is at least as important as the number of degrees. Of course, quality is notoriously difficult to define or to package in a policy initiative. Often-cited indicators of quality are well-prepared students committed to learning and helping each other learn; faculty and teaching assistants who enjoy and are rewarded for teaching; thoughtful, interactive curricula; well-maintained equipment and facilities for students to experience "real-life" bench research; and time and money for students to immerse themselves in full-time study. Experiencing research as an undergraduate is one of the most effective means of luring students to a career in science (or helping them discover early that they are not suited for such a career).[11] The National Science Foundation has designed many small but effective programs to improve quality. Federal mission agencies also have programs; and there is much scattered activity within individual institutions, industry, local companies, professional societies, and some States.

Some colleges have particular success in sending their graduates on to Ph.D.s in science and engineering. These nurturing environments are particularly important for women and minority students. The characteristics of these environments are individual attention to student development, undergraduate research participation, and a commitment to quality teaching. Such characteristics can be replicated. Federal policies can help institutions improve the quality of instruction with funding and incentives for undergraduate research, cooperative education, instruction and laboratory equipment and facilities, and faculty and institutional development. Nevertheless, it helps to start with bright, motivated students, and then invest in them.

Graduate Education

As students weigh graduate study and a research career, they consider both economic and noneconomic factors. Salary is one consideration among many in the career choices of aspiring academic researchers. The expectation of a rewarding research career is high on a list that includes the traditional rewards of university research: intellectual freedom, security of tenure, and the creative challenges and social

---

11. Janet Lanza, "Whys and Hews of Undergraduate Research," Bioscience, vol. 38, No. 2, February 1988, pp. 110-112.

pleasures found in the university environment.[12] Even so, a small fraction of baccalaureate-level scientists and engineers elect to pursue science or engineering doctorates at more than 330 institutions.

Most fields of study in the sciences, as distinguished from engineering, are oriented toward the academic job market, even though only one-half of all scientists work in academic institutions. The Ph.D. is the entry professional degree in these fields. Since the early 1970s, however, the academic job market in many fields has stagnated, as growth in undergraduate enrollments has slowed. Graduate enrollments have been sustained largely by foreign students who have helped compensate for the decline in enrollments by U.S. citizens.

Strategies to increase the number of American graduate students focus on bringing more women and minorities into engineering. While the participation of women in engineering increased rapidly during the late 1970s, it seems to have plateaued. A “chilly climate” still prevails on campus. Role models are too few, and access to career opportunities and salaries are still perceived as gender-linked in science and engineering, perhaps even more so than in business or law.[13]

The environment in which graduate study and academic research takes place is undergoing structural change, which may affect the attractiveness of research as a potential career. In the past two decades, an emphasis on applied research has transformed universities’ mission; undergraduate teaching and basic research have suffered. The faculty turnover expected in the 1990s, as the postwar generation of faculty retires, may present an opportunity to renew the commitment to teaching as fundamental to the academic enterprise.[14] Unfortunately, the research university does not seem to value teaching and “community service" as much as research (grant-getting and publishing). And this reward system seems largely impervious to change.

---

12. Alan Porter et al., “The Role of the Dissertation in Scientific Careers, ’f American Scientist, vol. 70, September-October 1982, pp. 475-481.
13. Nadya Aisenberg and Mona Barrington, "A 2-Tier Faculty System Reflects Old Social Rules That Restrict Women% Professional Develop merit,” *The Chronicle of Higher Education*, Oct. 26, 1988, p. A56; and Roberta M. Hall and Bernice R. Sandier, *Out of the Classroom: A Chilly Climate for Women?* (Washington, DC: Association of American Colleges, Project on the Status and Education of Women, October 1984).
14. Betty M. Vetter, “Replacing Science and Engineering Faculty in the 1990s,” presented at the Conference on Undergraduate Research, Carlton College, Northfield, MN, July 13, 1988.

The supply of engineers is of widespread concern because of the pivotal role that engineers play both in research and in bringing new technological developments into production and the global market. Increasingly rapid technological progress shortens the half-life of engineering knowledge, as educators struggle to keep apace with the demand for engineers freshly trained in the latest theories and techniques.

Because students are sensitive to the current job market rather than opportunities awaiting them when they graduate, the supply of new graduates is often mismatched to demand. There are shortages in some specialties, which stem from rapid growth in demand (and lags in supply response). Such transitory shortages seem unavoidable. Because of these shifts and mismatches, maintaining a strong enrollment base is important. Overall, the supply of engineers appears adequate. However, student interest in engineering is declining slightly, reflecting a softening of the job market relative to the market-driven boom in the late 1970s, as well as what some sense is a deeper malaise.[15]

Options for increasing the supply of engineers include both retraining and upgrading the education of technicians and technologists. Retraining of engineers in oversubscribed specialties, and of engineers in nonengineering jobs such as management, can help meet changing demand. Retraining, like other strategies, however, is not cost-free. New information education technologies, particularly video and satellite-based systems, which can cheaply and quickly reach engineers or technicians at their workplace, can help boost the supply and quality of engineers through retraining.[16]

A prominent issue in engineering is the large and growing presence at the graduate level of foreign students. Over one-half of graduate students are foreign. This is due, most believe, to the relative lack of interest on the part of American students in pursuing low-paying graduate study; the costs incurred and salary foregone is not perceived as worth the entry-level pay in academia. Instead, Americans seek lucrative,

15. "For Engineers, 4 Years' College Not Enough, Says MIT Dean," *Engineering Times,* December 1988, p. 5; and "Engineering Curricula to Get NSF-Funded Revamps, " *Engineering Times,* December 1988, p. 5.

16. National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988). Attracting scientists from nearby disciplines and keeping more active engineers from leaving the profession are related strategies for ensuring the future supply of engineers.

interesting positions in industry working with the latest equipment. About one-half of these foreign graduate students in engineering stay on in the United States in academia and industry. They make enormous contributions as graduate students and later as full-fledged engineers and researchers.

Controversy, however, arises in several areas. Although foreign students are widely regarded as competent researchers, many come with poor English and cultural biases which detract from their effectiveness as teaching assistants and colleagues. In response, universities have established English language requirements and courses to help acculturate foreign graduate students.[17]

In the absence of modifications in immigration policy and visa status, the proportion of foreign graduate students will continue to haunt some employers recruiting engineers for defense-related projects. Most such projects are open only to U.S. citizens. Some argue that, given the great benefits of foreign engineers to U.S. universities and industry, the United States should encourage not only students on temporary visas but also their eventual permanent immigration. On the other hand, there is some insecurity in relying on foreign students for critical knowledge (especially those on temporary visas who might unexpectedly return home). A corollary problem is the "draining" of highly -educated people from their native countries. Foreign engineers (and scientists) have been an invaluable source of talent in the past, and encouraging **study and immigration does not preclude trying to increase** the interest of U.S. students in engineering.

The number of U.S. engineering Ph.D.s increased slightly in 1986 and again in 1987, and graduate enrollments are rising; these figures, however, follow a long decline. Most proposals to attract more American students start with increasing pay for graduate students, so that stipends are at least one-half of what a baccalaureate could earn in industry. During the early 1980s, the years of strongest recent demand for engineers, some universities created special pay scales to recruit and retain engineering faculty; these seem to have helped.

The participation of Blacks and Hispanics in engineering, as well as the physical sciences, shows little sign of substantial increase. (Asian-Americans, on the other hand, are more likely than whites to major in engineering and go on to graduate study.)

---

17. National Research Council, *Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues* (Washington, DC: National Academy Press, 1988).

Although special programs at all levels of education have spurred extraordinary increases in Black and Hispanic students' interest in engineering, Blacks are still more than twice as likely as whites to drop out of an engineering major. Programs such as California's Minority Engineering Program, which has tripled participants' likelihood of persisting to a degree in engineering, succeed in retaining students in the pipeline.[18]

While leadership must come from university faculty and administration, external aid can make a difference. That aid can be money, but it also can be equipment and staff loans. The Federal Government can also assist by publicizing intervention programs, as well as sponsoring, evaluating, and replicating successful ones.

Cooperative education and other engineering-related work experience is valuable, too, but is neither widespread nor well institutionalized. The Federal Government employs many "co-op" students, and can give students access to unique work opportunities in Federal laboratories. In the 1970s, Federal funding for cooperative education expanded university programs; in the wake of decreased funding, new incentives for business and industry participation will be needed to create opportunities for students to pursue cooperative education.

Federal programs for engineering faculty, including research and young investigator support, industry-university exchange programs to bring industry engineers into academia, and engineering curriculum development, all enhance the quality of faculty and the education they deliver.

---

18. Raymond B. Landis, *Academic Gamesmanship: Becoming a "Master" Engineering Student* (New York, NY: National Action Council for Minorities in Engineering, 1987).