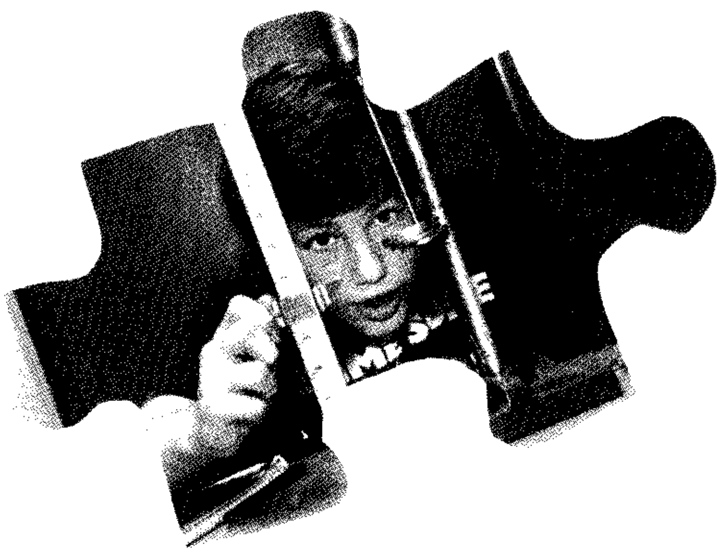
CHAPTER 7

Human Resources for the Research Work Force



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CHAPTER 7

Human Resources for the Research Work Force

My first priority is to create an environment in which talented young people choose careers in health sciences research. . . . My second priority would be to fashion a system in which talented, more senior researchers could obtain stable funding for their best work. Those two priorities cannot be achieved without setting some limits and making difficult choices.

Leon Rosenberg[1]

Introduction

The scientific education system in the United States, especially at the doctoral level, is the envy of the world. Foreign nationals continue to seek degrees in science and engineering at U.S. institutions at an ever growing rate, and this exemplary "production' of Ph.D.s has continued over at least the past 30 years.

The U.S. graduate research and education system trains new researchers and skilled personnel for all sectors of the Nation's work force (and for some countries abroad). While new researchers have traditionally been trained for faculty positions in academia, in fields like computer science, the demand for technical labor outside of academia is great. Some fields, like chemistry, also benefit from having a large set of potential academic and industrial employment opportunities. This diversity makes any labor market fluid and its forecasting difficult, but the major components can be analyzed.

This chapter focuses on Ph.D. production and employment in the United States and the *research* work force, as a subset of the total science and engineering work force. The educational 'pipeline' that prepares students at the K-12 through undergraduate level for doctoral study is discussed where needed.[2] First, the chapter discusses the overall shape of Ph.D. production in the United States, the Federal role in supporting graduate education, and the present employment prospects for new Ph.D.s. Second, the chapter focuses on projections for future employment of Ph.D.s, and then turns to training considerations for an uncertain future. The chapter concludes with a discussion of the Federal role in Ph.D. production and employment for the 1990s.

Photo credit: U.S. Department of Energy

Scientist mixes a chemical sample. Broadening the participation in research of traditionally underrepresented groups, such as U.S. minorities, is a central issue for the health of the research enterprise.

Baseline Data on Science and Engineering Degrees

Trends in the award of science and engineering (s/e) degrees highlight 20 years of growth in human

[1]Quoted in Dick Thompson, "The Growing Crisis in Medical Science," *Time*, Dec. 17, 1990, p. 21.

[2]An analysis of the higher education stages of the pipeline and how the Federal Government intersects with it is contained in U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering*, OTA-BP-SET 52 (Washington, DC: U.S. Government Printing Office, March 1989).

resources.[3] Scientific education has yielded a significant number of new Ph.D.s, yet the benefits of this education have not accrued equally to all groups and, therefore, to the Nation. Women and U.S. racial and ethnic minorities, despite gains in Ph.D. awards through the 1970s and 1980s, lag the achievement of white men. Relative to their numbers in both the general and the undergraduate populations, women and minorities are underparticipating in the research work force.[4] Foreign nationals on temporary visas are a growing proportion of s/e degree recipients.[5] National Science Foundation (NSF) data indicate the following trends.[6]

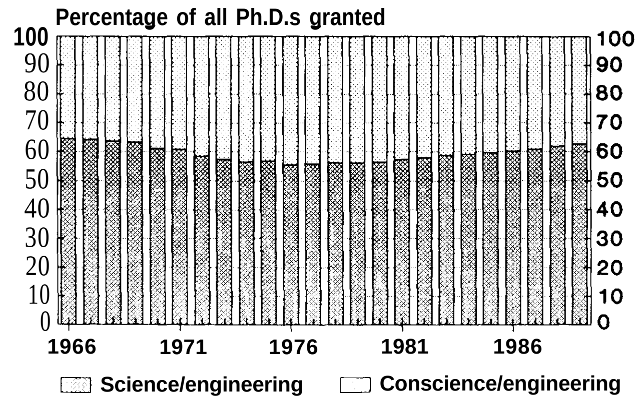
Degrees, Gender, Ethnicity, Nationality, and Fields of Study

The total number of Ph.D.s awarded in s/e has increased from 17,400 in 1977 to over 20,250 in 1988. In addition, the proportion of s/e Ph.D.s awarded as compared with Ph.D.s granted in all fields varied from 57 to 64 percent over the period from 1966 to 1988 (see figure 7-l).

Of the approximately 34,000 Ph.D.s awarded in 1988 (in all s/e and non-s/e fields), the distribution by *s/e field* ranges from ***2*** percent in environmental sciences to 15 percent in biological/agricultural (hereafter, "life") sciences. Trends in field shares are variable, showing percentage increases and decreases over the period 1966 to 1988 (see figure 7-2).

One in three college graduates earns the baccalaureate degree in an s/e field. By gender, men earn more baccalaureate degrees in s/e fields per thousand than women by a ratio of three to two.[7] In 1988, women earned 40 percent of baccalaureate degrees, 30 percent of master's degrees, and 27 percent of the doctorates awarded in s/e. At the Ph.D. level, this proportion represents more than a tripling since 1966 (see figure 7-3). (In non-s/e fields, however, women have achieved parity in Ph.D.s earned and exceed the numbers of 'men' awarded baccalaureate and master's degrees.)

Figure 7-1—Ph.D.s Granted, by Field: 1966-88



SOURCE: National Science Foundation, *Science* and *Engineering Degrees: 1966-88, A Source Book,* NSF 90-312 (Washington, DC: 1990), table 1; and National Science Foundation, Science and *Engineering Doctorates: 1960-89,* NSF 90-320 (Washington, DC: 1990), table 1. National Science Foundation, Science *and Engineering Degrees: 1966-88, A Source Book,* NSF *90-312* (Washington, DC: 1990), table 1; and National Science Foundation, *Science and Engineering Doctorates: 1960-89,* NSF 90-320 (Washington, DC: 1990), table 1.

Except for life sciences, psychology, and social sciences, the number of doctorates awarded to women is modest. In 1988, among U.S. citizens, men earned 90 percent of the engineering Ph.D.s, 63 percent of the science Ph.D.s, and 48 percent of the non-s/e Ph.D.s. In fractional terms, women now earn one in three life sciences and social sciences Ph.D.s and more than one of every two Ph.D.s awarded in psychology. From 1966 production rates, engineer-

[3] Although OTA uses the shorthand "scientists and engineers, " it recognizes the diversity of fields represented by the term. These fields are those used as degree-granting categories in the National Science Foundation's Science Resources Studies reports: engineering, physical sciences, environmental sciences, mathematical sciences, computer/information sciences, life (biological/agricultural) sciences, psychology, and social sciences.

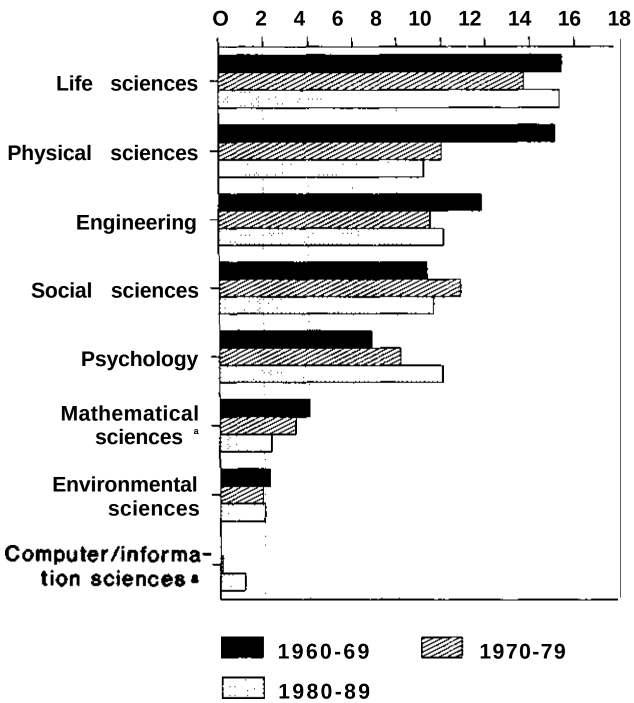
[4] Degrees alone tell an incomplete story of future supply of scientists and engineers. For example, college attendance rates of 18- to 21-year-olds vary by gender and race. Since 1972, 35 to 40 percent of whites of both sexes in the cohort have attended college with Black rates in the 25 to 30 percent range. By 1988, female attendance exceeded that of males and was rising, whereas male attendance of both races peaked in 1986-87 and has declined thereafter. See National Science Board, *Science & Engineering Indicators—1989* (Washington, DC: U.S. Government Printing Office, 1989), figure 2-2, p. 50. The National Science Foundation furnishes all data reported in the *Science & Engineering Indicators* report.

[5] For an overview, see Commission on Professionals in Science and Technology, *Measuring National Needs for Scientists to the Year 2000*, report of a workshop, Nov. 30-Dec. 1, 1988 (Washington, DC: July 1989), pp. 20-24. For more on graduate engineering education, see Elinor Barber et al., Choosing *Futures: U.S. and Foreign Student Views of Graduate Engineering Education (New* York, NY: Institute of International Education, 1990).

[6] National Science Foundation, science *and Engineering Degrees: 1966-1988—A Source Book*, NSF 90-312 (Washington, DC: 1990). Doctorate data are drawn from the multiple agency-sponsored Survey of Earned Doctorates conducted under contract by the National Research Council and assembled and reported by the Division of Science Resources Studies of the National Science Foundation.

[7] This ratio has narrowed since 1966 when it was nearly 3.5 to 1. See ibid., table 55, p. 43. Also see Sarah E. Turner and William G. Bowen, "The Flight From Arts and Sciences: Trends in Degrees Conferred, " *Science*, vol. 250, Oct. 26, 1990, pp. 517-521.

Figure 7-2—Distribution of Doctorates by Science and Engineering Field, 1960-90 (by decade, in percent)



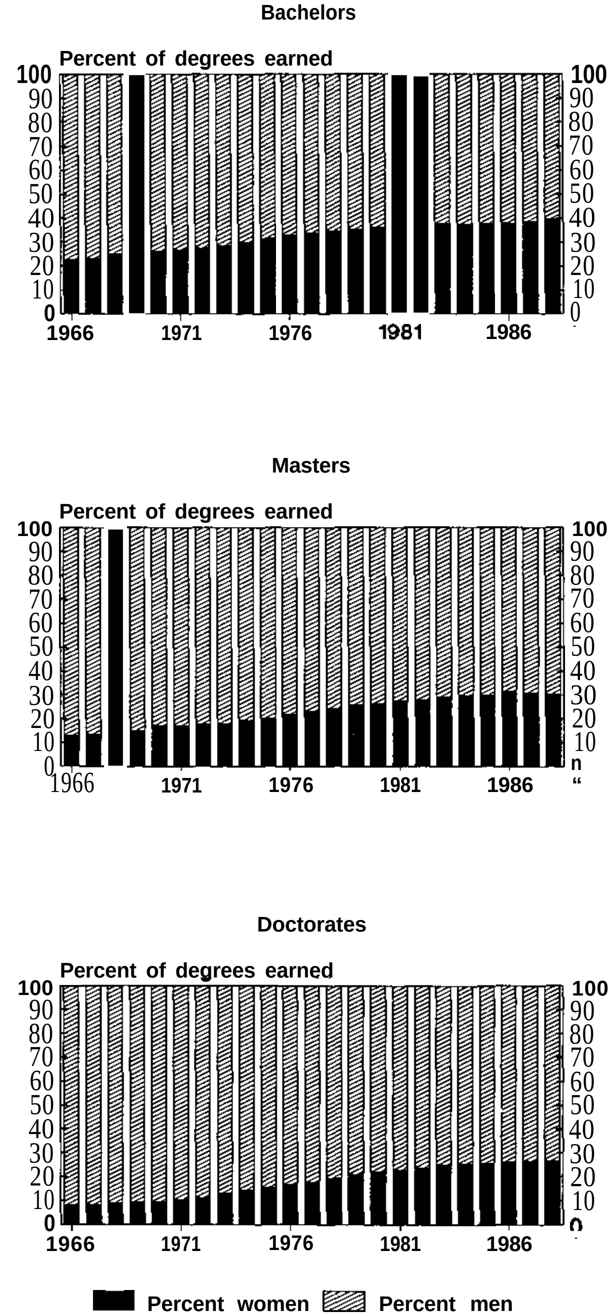
[a]Degrees in this field were not awarded until the late 1970s: before then, computer science was counted with mathematical sciences.

SOURCE: National Science Foundation, *Science and Engineering Doctorates: 1960-89,* NSF 90-320 (Washington, DC: 1990), table 1.

ing increased from virtually no awards to women to almost 7 percent in 1988, while physical sciences experienced a fourfold increase to 17 percent.[8]

The total number of Ph.D.s in s/e awarded to *minorities* rose from **560 in 1975** to 1,100 in 1988. However, trends by ethnic group are not as consistent. Black U.S. citizens earned 240 Ph.D.s in 1975, which rose to a high of 290 in 1979, but by 1988 had dropped to 230. Degrees awarded to Hispanics over the same period increased from 130 in 1975 to 320 in 1988, exhibiting predominantly steady increases each year. The most dramatic increase occurred within the Asian population, which recorded increases from 190 Ph.D.s in s/e in 1975 to 440 Ph.D.s in 1988, with gains posted in every year but one (1985).[9]

Figure 7-3-Science and Engineering Degrees, by Level and Sex: 1966-88



SOURCE: National Science Foundation, *Science and Engineering Degrees: 1966-88, A Source Book,* NSF 90-312 (Washington, DC: 1990), tables 3 and 4.

[8]National Science Board, op. cit., footnote 4, tables 23 and 25, pp. 25-26.

[9]Ibid., pp. 55-56. The numbers bave been rounded.

Foreign citizens on temporary visas earn increasing proportions of the s/e doctorates awarded by U.S. universities: one-quarter of all s/e Ph.D.s, and as much as 40 percent in engineering and mathematics.[10] The number of Ph.D.s awarded in s/e to foreign citizens on temporary visas increased from 2,700 in 1975 to 4,800 in 1988, with the most rapid gains in the 1980s. Foreign nationals on permanent visas, on the other hand, decreased from 1,200 in 1975 to 820 in 1984, but experienced a rapid rise to 1,100 in 1988. At the same time, the total for U.S. citizens dropped from 14,000 in 1975 to 12,800 in 1988, with the most rapid decrease in the late 1970s. During the 1980s, s/e Ph.D.s awarded to U.S. citizens showed no clear trends, ranging from a low of 12,600 (1987) to a high of 13,300 (1981).[11]

In summary, the total number of Ph.D.s awarded in s/e in the United States has increased by nearly 50 percent from 1977 to 1988. The numbers of women and minority recipients of Ph.D.s have also increased, with the greatest gains posted by women, Hispanics, and Asians, but with no gain by Blacks. Perhaps most dramatic is the increase in Ph.D. awards to foreign citizens on temporary visas, which almost doubled from 1978 to 1988. (For a comparison of national trends with the experiences of four research universities-public and private, and regionally dispersed—see box 7-A.)

Forms of Federal Support to Graduate Students

Clearly, graduate enrollments and the award of the Ph.D. in s/e depend on more than undergraduate degree attainment. Institutional practices and Federal policies play a significant role in graduate student support, completion of the doctorate, and employment aspirations. OTA notes the following trends.

Ever since the National Defense Education Act of 1958 (NDEA, Public Law 85-864) passed in the wake of the Sputnik launch, the Federal Government has been pivotal in pre- and postdoctoral support of science, engineering, and indeed, non-s/e students.[12] Additional programs were soon established by NSF, the National Aeronautics and Space Administration (NASA), the National Institutes of Health (NIH), and other Federal agencies. This period of growth, beginning in the 1960s, in Federal programs offering *fellowships* (portable grants awarded directly to students for graduate study) and *traineeships* (grants awarded to institutions to build training capacity) was followed by decreases in the 1970s.[13] In the natural sciences, these declines were offset by the rise in the number of *research assistantships (RAs)* awarded on Federal research grants. Federal support to the humanities and social sciences has always been comparatively less since, outside of NDEA, traineeships and fellowships were offered for the natural sciences, and research assistantships are rarely supported on social sciences or humanities grants. During the 1980s, other sources of support, including loans and family contributions, remained constant (see figure 7-4).

In the 1980s, RAs became the principal mechanism of graduate student support, increasing at 5 percent per year since 1980 (except in agricultural sciences, where RAs have actually declined). This trend is consistent with the growing "research intensiveness' of the Nation's universities: more faculty report research as their primary or secondary work activity, an estimated total in 1988 of 155,000 in academic settings.[14]

If the Federal agencies were to change the mix of support to graduate students, first by increasing the number of portable fellowships, the concentration of support in the major research universities would be reinforced. On the other hand, if the government were to increase the number of traineeships, Federal support could be directed to a broader set of institutions. No particular mix of support mecha-

[10] Ibid., pp. 46, 56.

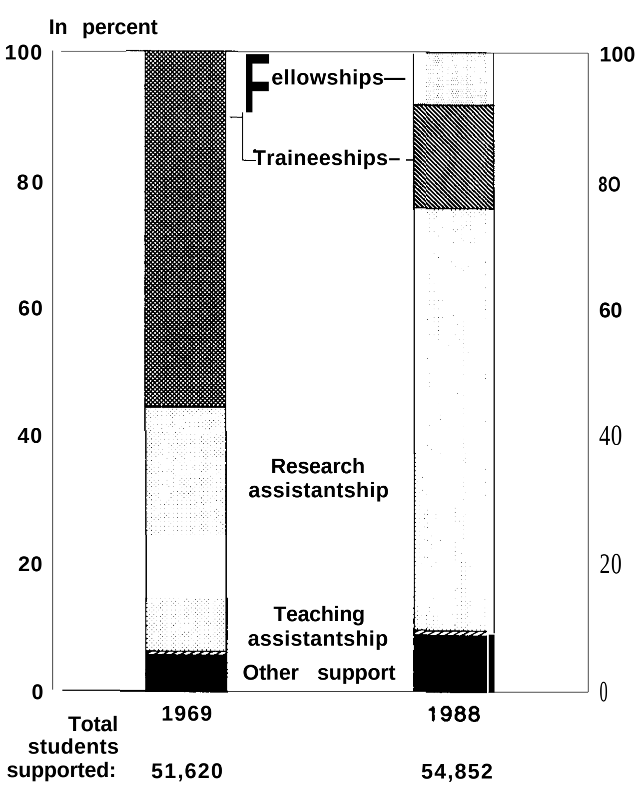
[11] Note that the numbers of Ph.D.s awarded to U.S. citizens and to foreign citizens on temporary and permanent visas do not add up to the number given for all Ph.D.s awarded. Roughly 7 percent of the total number of Ph.D.s are of unknown citizenship. Lawrence Burton, Science Resources Studies, National Science Foundation, personal communication, Dec. 10, 1990.

[12] For details, see U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force,* OTA-TM-SET-35 (Springfield, VA: National Technical Information Service, December 1985), pp. 44-49.

[13] Association of American Universities, *The Ph.D. Shortage: The Federal Role* (Washington DC: Jan. 11, 1990), pp. 15-16.

[14] These 155,000 represent 37 percent of employed Ph.D. scientists and engineers in the United States in 1981'. There are several assumptions built into these estimates-that Ph.D.s are most likely to do research, that research is considered a "primary or secondary research activity" by survey respondents, and that (although R&D are coupled here) basic and applied "R," not "D" is performed in academic settings. National Science Board, op. cit., footnote 4, pp. 46, 57, 115.

Figure 7-4—Federal Support of Science and Engineering Graduate Students: 1969 and 1988
(by type of support)



NOTE: Fellowships and traineeships were not reported separately in 1969.

SOURCE: National Science Board, *Science & Engineering Indicators—1989,* NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 2-18; and National Science Foundation, *Graduate Student Support and Manpower Resources in Graduate Science Education, Fall 1969,* NSF 70-40 (Washington DC: September 1970), table C-1 la.

nisms appears to alter the decision to pursue graduate study .15

Employment of Researchers

Since 1980, NSF estimates that the total s/e work force (baccalaureate, master's, and Ph.D. degree recipients) has grown at 7.8 percent per year, which is four times the annual rate of total employment of 1.8 percent. Scientists and engineers represented 2.4 percent of the U.S. work force in 1976 and 4.1 percent in 1988.[16] Almost 2.0 million scientists and 2.6 million engineers were employed in the s/e work force in 1988. In addition, almost 25 percent of all scientists and 10 percent of all engineers were employed in non-s/e jobs in 1988. At the doctoral level, scientists numbered 351,000, which is five times the engineers at 68,000. Total employment for doctoral scientists and engineers grew by nearly 5 percent per year from 1981 to 1987.[17] The percentage of foreign nationals who remain in the United States after receiving their Ph.D.s remained at roughly 50 percent through the latter half of the 1980s.

A pivotal employment sector for Ph.D. s/e researchers is academia. From 1977 to 1987, the number of Ph.D. scientists and engineers engaged in academic research increased by 65 percent. Figure 7-5 shows that life scientists accounted for one in three doctoral scientists and engineers on campus, a proportion unchanged in a decade, while figure 7-6 indicates average annual growth rates by field, with computer and information scientists leading the way.

The academic research work force in 1987 was 90 percent white (both sexes) and 84 percent male. Overall participation in academic research by minorities is bifurcated-9 percent is Asian and expanding, 2 percent is Black and Hispanic and barely inching upward. The most encouraging statistics are for Black women who, in 1987, represented 31 percent of Black Ph.D. scientists doing research in the academic sector.

NSF estimates a 51-percent increase, from 1977 to 1987, in the number of s/e doctorates engaged in *basic research,* regardless of employment sector. Four out of five (79 percent) worked in academia in 1987 (see figure 7-7); industry employs 8.6 percent; the Federal Government employs 6.7 percent; nonprofit institutions support 3.5 percent; and other groups employ the final 2.6 percent.

[15] 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), p. 88. The administration's fiscal year 1992 budget, however, proposes to consolidate graduate student financial aid programs at the Department of Education into a single National Graduate Fellowships Program (NGFP) and place it under the discretionary authority of the Secretary of Education. Included under NGFP is the Graduate Assistance in Areas of National Need Program to support physical science and engineering students ($25 million in fiscal year 1991). See "FY 1992 Budgets for Social and Behavioral Science Research," *COSSA Washington Update,* vol. 10, Mar. *4, 1991,* pp. 10-11.

[16] National Science Board, op. cit., footnote 4, p. 67.

[17] Ibid., p. 116.

Box 7-A—institutional Variations on National Trends: Graduate Enrollments at Four Research Universities

While national trends in graduate enrollments, demography, support, and distribution by field paint the "big picture,' they depersonalize and often mask how institutions (and their sponsors) influence those destined to join the research work force. Profiles of graduate student enrollments at four research universities-two public, two private-provide comparisons among key characteristics.[1]

In the 1980s, graduate enrollments grew by 18 percent nationally. By broad field, enrollments have, in percentage terms, grown steadily in engineering and mathematics/computer science, decreased slightly in the life sciences and more markedly in the social sciences, and been stable in psychology and the environmental sciences. But these national trends are not mirrored at the four universities examin ed by OTA: the University of Houston, the University of Califonia-Santa Barbara (UC-Santa Barbara), Carnegie-Mellon University, and the Massachusetts Institute of Technology (MIT) (see table 7A-l).

Growth in enrollments from 1980 to 1988 range from 43 percent at Carnegie-Mellon to 13 percent at UC-Santa Barbara. MIT's enrollment declined by 2 percent. The University of Houston, while increasing its graduate student population by one-third, experienced the largest growth in mathematics/computer science. At Carnegie-Mellon, there was virtually no change in the distribution by broad field during the decade. At MIT, engineering enrollments declined (but over one-half of all graduate students there are pursuing engineering degrees), and at UC-Santa Barbara the number of mathematics/computer science students nearly tripled.

Examined in terms of demographic characteristics, the graduate student populations at all four universities reflect national trends, but at different levels:

- Nationally, the proportion of women is up slightly to 32 percent. At the four universities highlighted here the trend is similar, but enrollments of women averaged one-quarter of all science and engineering (s/e) students.
- Foreign nationals comprise almost one-half the graduate s/e students at Houston, and one-third at MIT and Carnegie-Mellon. Nationally, foreign students were 26 percent of the graduate student population in 1988.
- Among U.S. citizens, minorities represent one-quarter at Houston, but only 13 to 14 percent at the other three universities. The national average, unchanged since 1983, was 18 percent.[2]

In actuality, little is known about Ph.D. supply.[3] In the words of the National Research Council: "Basic descriptive statistics such as the percent of entering doctoral students who never complete the degree are unknown. More complicated issues such as determinants of degree completion (e.g., financial support, family responsibilities, demography, and time to complete the degree) remain unanswered."[4] National trends in graduate student enrollments tell only part of the story of factors affecting the renewal of human resources in science and engineering.

[1] The data reported below are based on unpublished National science Foundation data compiled by the Division of Science Resources studies.

[2] The national data are drawn from National Science Board, *Science & Engineering Iti'caters---l989* (Washington, DC: 1989), pp. *215-216,* tables 2-7 and 2-8.

[3] This sample of four institutions alone suggests that research-intensive universities may under-enroll women and U.S. minorities and over-enroll foreign nationals m graduate science and engineerin g study relative to national trends. OTA's analysis of University of Michigan and Stanford University is consistent with these findings across all fields of science and engineering as well, with women compromising 28 and 22 percent, respectively, and foreign nationals 34 and 30 percent, of graduate enrollments. But generalizations are premature until more systematic analysis is undertaken.

[4] Alan Fechter, executive director, Office of Scientific and Engineering Personnel, National " search Council, personal communication, Oct. 23, 1990.

Fields vary in their dependence on sectors of employment. Basic researchers with a Ph.D. in some fields-mathematics, sociology/anthropology, and economics— are employed almost exclusively in academia. Industry, in contrast, employed 19 percent of all engineers and 25 percent of computer scientists doing basic research in 1987. The field experiencing the largest percentage increase in industrial employment during the decade was the life sciences (in large part due to the biotechnology boom).[18]

[18] Ibid. The National Science Foundation also reports that retention of male doctoral scientists and engineers is the highest for the business/industry and university/college sectors, around 80 percent, after 14 years (see pp. 117-118 for a discussion).

Table 7A-l-Graduate Enrollment In Science and Engineering at Selected Universities, by Field: 1980-88

Year	Total students	Engineering	Social sciences	Life sciences	Math/ computer science	Psychology	Physical sciences	Environ-mental sciences
National totals								
1980	208,232	20.1 %	27.7%	21 .8%	7.3%	10.4Y0	10.7%	4.9%
1983	223,135	23.6	21.5	20.0	8.8	9.9	11.0	5.2
1986	236,741	24.9	19.9	19.2	10.6	9.3	11.4	4.6
1988	245,463	25.1	20.1	19.1	10.8	9.5	11.3	4.0
University of Houston								
1980	766	24.80/o	12.70/o	20.3%	9.5%	1 5.5%	14.3%	2.7%
1983	864	31.1	9.6	16.9	13.0	5.7	18.9	4.9
1986	1,165	29.0	9.5	13.6	13.7	14.2	16.5	3.4
1988	1,017	29,1	9.5	14.2	13.1	15.5	15.6	2.9
Carnegie-Mellon University								
1980	796	47.4%	18.80/0	2.9%	18.20/!	1.60/0	10.9%	0.0%
1983	965	44.0	21.7	3.2	18.8	2.1	10.3	0.0
1986	1,115	46.4	17.9	3.3	20.3	1.7	10.4	0.0
1988	1,137	45.8	18.6	3.5	19.5	2.5	10.0	0.0
Massachusetts Institute of Technology								
1980	3,904	62.0°/0	10.2%	7.5%	3.0%	0.8%	12.9%	3.5%
1983	3,795	61.6	10.8	7.1	2.9	0.9	13.0	3.6
1986	3,925	56.2	11.6	6.4	8.1	1.1	13.0	3.5
1988	3,827	54.0	11.9	6.3	3.5	1.4	13.9	3.5
University of California-Santa Barbara								
1980	1,142	25.20/.	27.8%	17.40/.	4.9%	4.5%	14.5%	5.6%
1983	1,178	27.6	25.6	16.0	4.8	4.1	16.1	5.9
1986	1,262	24.2	25.0	14.4	12.0	4.3	15.1	4.9
1988	1,293	28.3	22.0	14.6	13.4	3.7	13.9	4.0

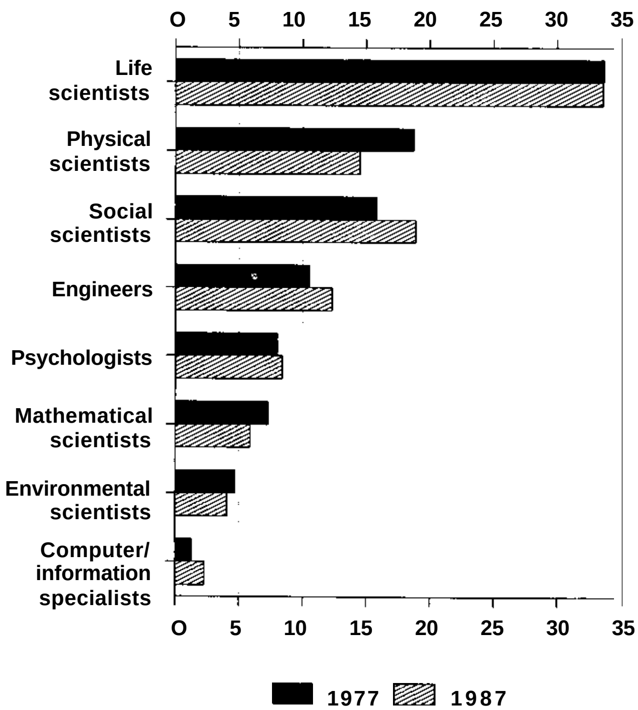
NOTE: Full-time students only.

SOURCE: National Science Board, Science & Engineering Indicators--1989 (Washington, DC: U.S. Government Printing Office, 1989), table 2-16, p. 228; and National science Foundation, Institutional Profiles of the University of Houston, Carnegie-Mellon University, Massachusetts Institute of Technology, and University of California-Santa Barbara, unpublished information, 1989.

Complicating the understanding of employment trends is that temporary, 1- to 2-year appointments are **a** tradition in some fields. Postdoctoral appointments are used both to augment the specialized skills acquired in doctoral study and to wait out poor employment markets.[19] The number of Ph.D.s taking postdoctoral positions in U.S. universities has grown 5 percent annually since 1980. The availability of these appointments expand with academic research budgets, and over one-half of these posi-

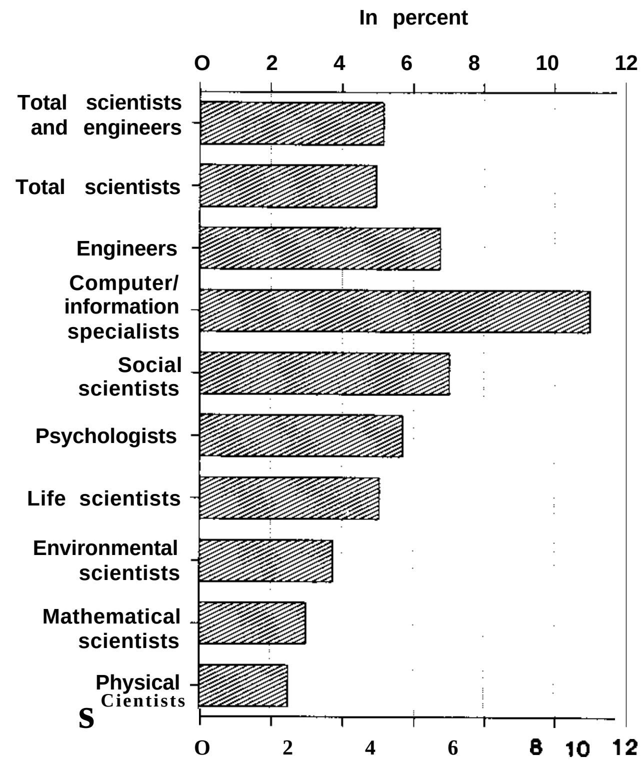
[19]Traditionally, the postdoctoral appointment is for 1 to 2 years. The last major national study of postdoctorates, however, is a decade old.This issue needs to be revisited empirically. For a national perspective, see Nationa1 Research Council, *Postdoctoral Appointments and Disappointments* **(Washington,** DC: National Academy Press, 1981). For a first-person perspective on how circumstances maybe changing, see Edward J. Hackett, "Science as a Vocation in the 1990s," *Journal of Higher Education,* vol. 61, May/June 1990, pp. 241-279.

Figure 7-5-Distribution of Doctoral Scientists and Engineers in Academic R&D, by Field: 1977 and 1987 (in percent)



SOURCE: National Science Board, *Science & Engineering Indicators-1989*, NSB 89-1 (Washington, DC: U. S. Government Printing Office, 1989), app. table 5-17.

Figure 7-6-Average Annual Percentage Growth Rate of Doctoral Scientists and Engineers in Academic R&D, by Field: 1977-87



SOURCE: National Science Board, *Science & Engineering Indicators-1989*, NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 5-17.

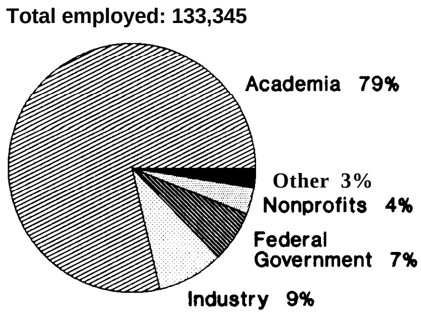
tions are located in the life sciences. Foreign citizens have been increasing their postdoctoral appointments at a rate twice that of U.S. citizens in the last decade.[20] Also, universities have increased the number of available nonfaculty research positions, and that the number of nonfaculty researchers as a percentage of the total number of Ph.D.s in s/e employed in academia rose from 14.8 percent in 1977 to 17.5 percent in 1987 (see box 7-B).

In sum, there is a steady stream of new entrants to the research work force. Almost 14,000 s/e Ph.D.s are granted each year by U.S. universities to U.S. citizens (nearly 13,000) or to foreign citizens who are permanent residents (over 1,000). Industry and academia have increased their employment of Ph.D.s in s/e over the past two decades, and by rates exceeding 5 percent per year in the 1980s. In addition, relatively temporary university positions, such as postdoctoral and nontenure-track research slots, have increased.

Historically, the Federal Government has played both a direct and indirect role in the production and employment of s/e Ph.D.s. Both as the primary supporter of graduate student salaries and tuition, and as an employer through the Federal laboratories and mainly through research grants, the Federal Government has perhaps the largest role in the s/e Ph.D. labor market. With changing demographics and demands on the research component of this labor

[20] National Science Board, Op. cit., footnote 4, p. 54. There is both a "push" and "pull" factor operating in the postdoctorates taken by non-us. citizens with Ph.D.s. They may be ineligible for employment in some sectors, e.g., defense, and they can be productive researchers while awaiting a change in visa status from temporary to permanent. S. 358, passed in the 101st Congress, would allow the annual number of employment-based visas to increase from 54,000 to 140,000. Up to 40,000 visas are reserved for academicians and others with "extraordinary" ability to work in the United States. An annual cap of 65,000 H-1, or temporary professional, visas was also imposed. See Janice Long, "U.S. Immigration Eased for Professionals," *Chemical & Engineering News*, vol. 68, No. 47, Nov. 19, 1990, p. 13.

Figure 7-7—Employment of Doctoral Scientists and Engineers in Basic Research, by Sector: 1987



SOURCE: National Science Board, *Science & Engineering krdicafors-1989,* NSB 89-1 (Washington, DC: U.S. Government Printing Office, 1989), app. table 5-19.

force, the Federal Government could redefine that role as more or less interventionist in the 1990s.

The Shape of the Future Research Work Force

In recent years, the scientific community and some Federal research agencies have intensified the call for increased support of human resources. One emphasis has been on the educational 'pipeline"—how to attract more elementary and secondary school students to science, mathematics, and engineering.[21] Since the school-aged population will begin to grow with the second baby boom in the mid-1990s, most research agencies have initiated programs that emphasize earlier stages in scientific education, especially at the secondary and undergraduate levels.[22] Not only will this population grow, but a larger proportion of it will consist of racial and ethnic minorities.

The Uncertainty of Ph.D. Projections

Another focus of concern is the state of graduate education in s/e. Some recent reports have projected that, in the 1990s, many scientific fields will experience shortages in the supply of Ph.D. researchers.[23] Based on demographic characteristics alone, NSF has estimated that the number of new Ph.D.s awarded in the natural sciences and engineering by U.S. universities (to U.S. citizens and foreign nationals) would rise from roughly 14,450 in 1988 to 15,600 in 1993, but then would decrease to 14,200 by the year 2010. This projection, based on a predicted ''shortfall' in natural science and engineering baccalaureate degrees, assumes little change in the proportion of U.S. doctorate-seeking students and that the number of Ph.D.s awarded to foreign nationals remains at 4,500 per year.[24]

To convert these figures into a future supply of Ph.D.s for the scientific labor market, one must assume that some proportion of foreign nationals will seek to remain in the United States for employment. Most estimates assume that the current level of 50 percent will hold throughout the 1990s, while noting that increased scientific sophistication of these students' native countries may eventually draw a larger proportion of them back home.

If the current demand for Ph.D.s in academia and industry, at over 12,000 per year, were to remain constant, then the aggregate supply of Ph.D.s in the 1990s would be more than adequate. (This would not mean, of course, that the distribution among s/e

[21]For a review of the factors influencing the early stages of the pipeline, see U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering,* OTA-TM-SET-41 (Washington DC: U.S. Government Printing Office, December 1988); and D.E. Chubin, "Misinformation and the Recruitment of Students to Science,'*Bioscience,* vol. 40, No. 7, July/August 1990, pp. 524-526.

[22]The National Science Foundation has been particularly active. See Erich Bloch, ''Education and Human Resources at the National Science Foundation" *Science,* vol. *249,* Aug. 24, 1990, pp. 839-840; National Science Foundation "Background Material for Long-Range Planning: 1992- 1996," NSB-90-81, prepared for a meeting of the National Science Board, June 14-15, 1990, p, A-5; Ward Worthy, "Research Universities Pay More Heed to Freshman Science," *Chemical& Engineering News,* vol. 68, No. 18, Apr. 30, 1990, pp. 27-28; and Mac Van Valkenburg, "Tinning Off Students: Our Gatekeeper Courses," *Engineering Education,* vol. 80, No. 6, September/October 1990, p. 620. For a new conceptualization of undergraduate recruitment and retention, see Sheila Tobias, They're *Not Dumb, They're Different: Stalking the Second Tier* (Tucson, AZ: Research Corp., 1990).

[23]For example, see Association of American Universities, op. cit., footnote 13; Janice Long, "Changes in Immigration Law Eyed To Avert Shortage of U.S. Scientists," *Chemical& Engineering News,* vol. 68, No. 34, Aug. 20, 1990, pp. 19-20; and Richard C. Atkinson, "Supply and Demand for Scientists and Engineers: A National Crisis in the Making,' *Science,* vol. 246, Apr. 27, 1990, pp. 425-432. Labor economist Michael Finn has noted that "shortage' is a relative concept. "Increasing shortage of scientists and engineers' means that they will be harder to find than they are now, or were in the recent past. The difficulty in measuring shortage is that hiring standards and personnel budgets adapt to supply and demand conditions. See Michael G. Finn, "Personnel Shortage in Your Future?"*Research-Technology Management,* vol. 34, No. 1, January-February 1991, pp. 24-27.

[24]Cited in Atkinson, op. cit., footnote 23.

Box 7-B—The Unfaculty: Who Are They and Why Should We Worry?

Graduate student enrollment increased rapidly during the 1960s, followed by a decline in the rate of increase in the 1970s and early 1980s. Because undergraduate and graduate student enrollment levels are closely associated with funding available for faculty salaries, it is not surprising that there was a decline in faculty job openings and a rise of ''academic marginals '' or research professionals, most possessing the Ph.D. but lacking a faculty appointment. This cadre has also been referred to as the "unfaculty,' ''unequal peers," or "research associates. " In an effort to maintain an appropriate research base in the face of increasingly tight budgets, universities employ academic marginals on short-term contracts. These new nonfaculty positions do not depend on enrollment levels and afford the university flexibility in fulfilling its research needs since marginal positions are more readily emptied and reallocated than are tenured and tenure-track faculty.[1]

Who are these academic marginals? Many are postdoctoral fellows who, unable to secure faculty positions, remain in the university setting for an indefinite period of time. These positions might be viewed as extensions of the scientific apprenticeship system, which includes graduate education and postdoctoral training.[2] Of the fiscal year 1972 graduates who had taken postdoctoral appointments, approximately one-third had prolonged their appointments because they could not find other desirable employment.[3] Consequently, these professional research scientists tend to be highly qualified and capable, most earning Ph.D. s from reputable research institutions, have impressive publication records, and are supported by National Institutes of Health and National Science Foundation (NSF) grants.[4] Yet, academic marginals are not recognized as full faculty members; they receive none of the amenities and privileges of faculty and, more important, are ineligible for tenure.

The inferior status associated with the unfaculty fosters negative feelings and tensions within the research community. Comparatively low salaries, little job security, and limited ''rights' to laboratory and office space or seed money and equipment all contribute to an environment in which the marginal scientist commands little respect from his or her full faculty peers. In fact, academic marginals often are dependent on faculty to provide part-time teaching or research that augments employment. Similarly, the academic marginal might find it difficult to establish him or herself in the scientific community at large: lacking an established laboratory and the accompanying prestige, marginal scientists have a ''. . . longer row to hoe than most . . . [and] have to be more perfect.

Standards vary on the research status of unfaculty and are a source of debate on many campuses. For example, research associates at Stanford University cannot act as principal investigators on research grants, which prohibits

[1] U.S. Congress, Office of Technology Assessment, *Higher Education for Science and Engineering*, *OTA-BP-SET-52* (Washington, DC: U.S. Government Printing Office, March 1989), p. 176,

[2] Edward J. Hackett, "Science in the Steady State: The Changing Research University and Federal Funding," OTA contractor report, 1987, p. 18. Available through the National Technical Information Service, #PB 88-177 928/AS.

[3] National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981), p- 225.

[4] Hackett, op. cit., footnote 2; and Albert H. Teich, ''Re search Centers and Non-Faculty Researchers: A New Academic Role," *Research in the Age of the Steady-State University*, Don Phillips and Benjamin Shen (eds.) (Boulder, CO: Westview, 1982), p. 100.

[5] See Edward J. Hackett, "science as a Vocation in the 1990' s,' *Journal of Higher Education, vol. 61,* May/June 1990, pp. 253-254.

fields would be ''correct. ' However, these calculations further project that the demand for Ph.D.s, which has been rising in the 1980s, will continue to increase. Several factors are cited: 1) replacement of currently employed s/e researchers due to retirements and deaths; 2) rising college and university enrollments in the mid-to-late 1990s to accommodate the second baby boom (therefore requiring more faculty); and 3) increasing Federal and industrial investment in R&D, if only at a moderate rate.[25]

[25] Research universities have the resources to plan for possible discontinuities in faculty age and tenure status. Other categories of institutions, especially comprehensive universities and 4-year colleges, will have less latitude in coping with imbalances in faculty supply and demand, which may be exacerbated with recision of the mandatory retirement law in 1993. Some alternatives, including the consolidation or elimination of departments and how, if at all, retiring faculty will be replaced, are discussed in Marcia Barinaga, "Howard Schachman Fights Retirement," *Science,* vol. 249, Sept. 14, 1990, pp. 1235, 1237; Constance B. Bouchard, "The 'Lost Generation' of Scholars Can Help Colleges Avoid the Looming Faculty Shortage, " *The Chronicle of Higher Education,* vol. *37, No. 12, Nov. 21, 1990,* pp. B1-B2; and Courtney Leatherman, "End of Mandatory Retirement Policies Seen Having Little Effect on Professors," *The Chronicle of Higher Education,* vol. *37, No. 17,* Jan. 9, 1991, pp. A13-A14.

them from gaining a history of funding with any Federal research agency. (This arrangement is fairly typical for research associate positions across the United States.)

It is possible that academic marginals are merely the product of a research environment that is shifting its focus and reevaluating its needs. But evidence that women have long been marginalized---less likely than men to land faculty posts or receive tenure once in them--in scientific research is unequivocal.[6] So funding pressures alone cannot explain swelling of the ranks of the unfaculty. Like the rest of the research work force, a panoply of demographic and funding changes may redefine the perceived needs of research universities. The status of those funded entirely on soft money may be reassessed as the costs of sustaining research units are scrutinized by academic administrators.

Surprisingly, national data beyond per-investigator costs are scarce on various ‘ ‘production’ units of research. This includes the extent to which the ranks of academic marginals are growing. Unpublished data on research personnel at 4-year colleges and universities compiled by NSF (which warns that the data may not be comparable for different years) are presented in table 7B-1. Over the period 1977 to 1987, the proportion of Ph.D. s without faculty rank grew slightly. Growth in the number of unfaculty, up 15,000 in the decade to a total of 37,000, suggests that this is a sizable reserve research labor force to augment university faculty capabilities. Beyond that, little is known about:

Table 7B-1—Research Personnel at 4-Year Colleges and Universities (based on self-identification)

	1977	1981	1987
Ph.D.s with faculty rank (assistant, associate, full)	85.2%	83.90/o	82.5%
Ph.D.s without facuity rank (includes postdoctorates)	**14.80/0**	**16.1 %**	**1 7.5%**
Totai number	**157,000**	**179,000**	**209,000**

SOURCE: National Science Foundation, Science Resources Studies Division, unpublished **data, July 1990.**

1. the cost to the Federal Government, which pays the salaries of unfaculty who are supported on research grants;
2. the career paths and prospects of the unfaculty; and
3. the possible mobilization of the unfaculty in the face of impending faculty retirements in the 1990s and projected shortages of Ph.D. scientists and engineers early in the next century.

Until better information is collected and analyzed on the unfaculty, Federal policymakers must worry about who they are and how they affect the university research economy of the 1990s.

[6]See Margaret W. Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* (Baltimore, MD: The Johns Hopkins University Press, 1982); Pnina G. Abir-Am and Dorinda Outram (eds.), *Uneasy Careers and Intimate Lives: Women in Science, 1789-1979* (New Brunswick, NJ: Rutgers University Press, 1987); and Vivian Gornick, *Women in Science: 100 Journeys Into the Territory,* revised ed. (New York, NY: Simon & Schuster/Touchstone, 1990).

However, OTA cautions those who wish to use these projections to predict future supply and demand for researchers. Projections of shortages and surpluses in the Ph.D. s/e work force are notoriously unreliable.[26] As OTA recently concluded:

> The job market for Ph.D.s is unusual. While it responds to demand (in particular, national R&D funding) and to immediate research and training support, the supply is particularly sensitive to Federal policies. As for quality, at the margins talent can be lured or discouraged to relieve shortages and surpluses.[27]

In addition, predicting the demand for academic researchers is extremely complex.[28] As discussed above, such predictions must include demographic changes, immigration trends, anticipated retirements, and the orientations and intentions of new entrants to the research work force, as well as shifting Federal priorities and available research funding. All of these are subject to change, and may

[26]OTA reached this conclusion on the basis of examining various models of academic and industrial markets. See Office of Technology Assessment, op. cit., footnote 12, especially chs. 3 and 4. Recent independent confirmation of this conclusion comes in a critique of a National Science Foundation model developed by its Policy Research and Analysis Division. See Alan Fechter, "Engineering Shortages and Shortfalls: Myths and Realities, " *The Bridge,* vol. 20, fall 1990, pp. 16-20.

[27]Office of Technology Assessment op. cit., footnote 2, p. 160.

[28]Ted I.K. Youn, "Studies of Academic Markets and Careers: An Historical Review," *Academic Labor Markets and Careers,* David W. Breneman and Ted I.K. Youn (eds.) (Philadelphia, PA: The Falmer Press, 1988), pp. 8-27.

vary by type of educational institution one attends, the field of Ph.D., the region of the country in which one seeks employment, and so on. Sorting these factors compounds the burdens with which policymakers and educators must cope.

In general, projections also do not take into account market adjustments:

> Most of the simulation models used to assess these labor markets assume . . . that if an imbalance occurs between supply and demand, nothing will occur to correct it. In fact, history demonstrates that these labor markets do tend to equilibrate. Thus, projected imbalances derived from such models-both shortages and surpluses--are always overstatements of what actually will be experienced.[29]

Finally, projections of future retirements and job availability in industry vary to a large extent by field. For instance, some expect faculty shortages to be higher in the humanities and social sciences than in the mathematical and physical sciences, with no shortages foreseen in the biological and behavioral sciences.[30] Also, the health of the pharmaceutical and related industries has a large effect on employment prospects for Ph.D.s in medical and chemical fields. These factors must be taken into account by Federal policies that address projections of shortages. As science policy statesman Harvey Brooks puts it:

> Most projections are based on extrapolations of recent history, usually considering only first derivatives, with little attention to second derivatives, which cannot be accurately estimated anyway. In fact the projection type of exercise has more often than not contributed to the tendency of the technical manpower production system to overreact, building up alternate surpluses and deficits owing to the delayed response of the educational pipeline to the conditions in the market.[31]

Given the uncertainty of projections, OTA finds that concentration on the preparedness of the pipeline to produce Ph.D.s (i.e., increasing the number of undergraduates earning baccalaureates in s/e) is the most flexible policy .32 If shortages begin to occur in a particular field, prepared undergraduates could be induced by increased graduate support to pursue a Ph.D. in that research area, and Ph.D. production would increase 4 to 7 years later. In addition, those scientists who would have otherwise left the field might stay longer, those who had already left might return, and graduate students in nearby fields could migrate to the field experiencing a shortage.[33] (These are all signals of opportunity sent by the market.)

If shortages do not materialize, then the Nation's work force would be enhanced by the availability of a larger number of highly skilled workers. Research in the United States would also benefit by the training of a larger number of baccalaureates in the sciences, a significant percentage of whom will choose to pursue scientific careers regardless of predictions of shortages, while others contribute their acquired knowledge to other occupations.

Concerns about the demographics of Ph.D. recipients could also be addressed. Laws that prohibit discrimin ation, such as Title VI of the Civil Rights Act of 1964 and Title IX of the Education Amendments of 1972, justify support to groups defined by the ascribed characteristics of race/ethnicity and sex,

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[29]Fechter, op. cit., footnote *26,* p. 19. Also see Eli Ginzberg, National Research Council, Office of Scientific and Engineering Personnel, ''Scientific and Engineering Personnel: Lessons and Policy Directions, " *The Impact of Defense Spending in Nondefense Engineering Labor Markets* (Washington, DC: National Academy Press, 1986), pp. 25=.12.

[30]For the academic administrator perspective, see Elaine El-Khawas, *Campus Trends-1988* (Washington, DC: American Council on Education, 1988); for a different perspective, see William G. Bowen and Julie Ann Sosa, *Prospects for Faculty in the Arts and Sciences* (Princeton, NJ: Princeton University Press, 1989). On the difficulty of applying national projections to regional, institutional, and field-specific academic markets, see Debra Blum, "Many Studies of Future Academic Job Market Are Said To Be of Little Use to Policymakers,'' *The Chronicle of Higher Education,* vol. 37, No. 23, Feb. 20, 1991, pp. A15, A19.

[31]Harvey Brooks, "Are Scientists Obsolete?," *Science,* vol. 186, Nov. 8, 1974, p. 503. Also see Constance Holden, "Do We Need More Ph.D.s, Or Is Fewer Really Better?" *Science,* vol. 251, Mar. 1, 1991, pp. 1017-1018.

[32]From a market perspective, Ph.D.s are skilled workers who experience low rates of unemployment. However, the Ph.D. worker thinks in terms of career paths. "Underemployment" means that the person is part of the Nation's labor force, but not working in a position that takes full advantage of his or her training and skills. The fit, in short, is not always good.

[33]Recall that 25 percent of scientists are in nonscience and engineering jobs. This is a huge potential reservoir corresponding to fluctuations in demand. In general, people with science and engineering taining are much easier to convert to other occupations than the reverse.

respectively .34 The 1980 reauthorization of the National Science Foundation also created the Science and Technology Equal Opportunities Act (Public Law 96-516). In it, Congress declared:

> . . . that the highest quality science over the long term requires substantial support, from currently available research and education funds, for increased participation in science and technology by women and minorities. The Congress further declares that the impact on women and minorities which is produced by advances in science and technology must be included as essential factors in national and international science, technology, and economic policies.[35]

With reauthorization of the Higher Education Act of 1965 scheduled for the 102d Congress, expectations are high that "significant and bold changes" will increase Federal aid to higher education institutions and students, especially historically Black colleges and universities.[36] This legislation empowers Congress and the research agencies that have devised programs targeted to enhance the participation of women and minorities in science to do even more.[37] Programs targeted to minorities, women, the physically disabled, and students in areas of the country where access to research institutions is limited, could help to expand the pool of potential scientists .38

Training for an Uncertain Research System

The unity of research and graduate teaching in U.S. higher education has sustained a vigor and creativity in research that is unparalleled in the world. The training of graduate students is also linked to the instruction of undergraduates in s/e. This section first looks at the connection between undergraduate teaching and research and then at the traditional academic research model and some alternatives.

Research and Undergraduate Teaching

Calls for a' 'new paradigm' for higher education in the 21st century are now emanating from the presidents of research universities.[39] Most of these reforms call for improved undergraduate education and ''. . . a better balance between research and teaching. ' A related need may also be to change the reward system of the university, since asking universities to augment the teaching of undergraduates may be misplaced if faculty continue to view this as a drain on their time that would be better spent doing research. This tension between the time spent on research and teaching at the major research universities and the use of graduate assistants as instructors for many lower level undergraduate

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[34]Controversy erupted in December 1990 over a Department of Education ruling that ''race-exclusive" scholarships are discriminatory and should be disallowed. This is seen as an assault on Title VI. Were such a ruling ever upheld, Federal aid and therefore college attendance by minority students could be jeopardized. See Scott Jaschik, "Scholarships Set Up for Minority Students Are Called Illegal," *The Chronicle of Higher Education*, vol. 37, No. 15, Dec. 12, 1990, pp. Al, A20; Kenneth J. Cooper, ''Administration Revises Race-Based Grant Rule,' *The Washington Post,* Dec. 19, 1990, pp. Al, A8; Ruth Marcus, "New Scholarship Ruling Caught in Legal Cross-Fire," The Washington *Post*, Dec. 18, 1990, p. A8; and Julie A. Miller, "Alexander Vows to Rescind Policy on Scholarships,' *Education Week,* Feb. 13, 1991, pp. 25,28.

[35]National Science Foundation Authorization and Science and Technology Equal Opportunities Act, Dec. 12,1980, 94 Stat. 3011.

[36]See Thomas J. DeLoughry, ' 'Colleges Welcome News That Rep. Ford Will Chair House PostSecondary Education Subcommittee, ' The Chronicle *of Higher Education,* vol. 37, No. 12, Nov. 21, 1990, p. A23.

[37]Office of Technology Assessment, op. cit., footnote 15, app. B.

[38]It is clear that market forces alone will not increase the participation of women, minorities, and the physically disabled in science and engineering. Policy intervention is required. Therefore, there is no inconsistency between letting the market operate for some segments of the student population while targeting other segments through recruitment and retention programs. For examples, see Linda Dix (cd.) *Minorities: Their Underrepresentation and Career Differentials in Science and Engineering*, workshop proceedings, National Research Council (Washington DC: National Academy Press, 1987); and Cynthia Lollar, "Access to Engineering: New Project for Students and Faculty With Disabilities," Science, vol. 251, Feb. 22, 1991, p. 952.

[39]Prominent among them are the two institutions that OTA studied as case examples, Stanford University and University of Michigan. See Karen Grassmuck, "Some Research Universities Contemplate Sweeping Changes, Ranging From Management and Tenure to Teaching Methods," *The Chronicle of Higher Education*, vol. 37, *No.* 2, Sept. 12, 1990, pp. Al,A29-31. Stanford's reforms include various programs, most funded by a $5 million gift to the university, ".. . designed to give faculty members ranging from graduate teaching assistants to senior professors better incentives to concentrate on effective instruction. ' See Kenneth J. Cooper, "Stanford President Sets Initiative on Teaching," *The Washington Post,* Mar. 3, 1991, p. A12.

[40]Grassmuck, Op. cit., footnote 39, p. A29. Also see Courtney Leatherman, ''Definition of Faculty Scholarship Must Be Expanded to Include Teaching, Carnegie Foundation Says, " *The Chronicle of Higher Education, vol. 37, No. 14,* Dec. *5, 1990,* pp. Al, A16-A17; and Alliance for Undergraduate Education, *The Freshman Year in Science and Engineering: Old Problems, New Perspectives for Research Universities* (University Park, PA: 1990).

Photo credit: Bob Kalmbach

Students at the University of Michigan walk on campus between classes. Undergraduate teaching is an important part of faculty responsibilities.

classes has caused some to question the health of undergraduate teaching at these universities.[41]

Another concern that stems from the tension between research and teaching is the relation between providing more funds for basic research and improving both the institution's research performance and teaching capability. A common perception during the 1960s was that Federal dollars that supported research also benefited undergraduate teaching because these top researchers would communicate their excitement about developments ''at the laboratory bench" to undergraduate and graduate students alike. In the 1980s, with the separation between research and undergraduate education becoming more pronounced at many research institutions (Particularly with many faculty "buying out" of teaching responsibilities when awarded a large research grant), the connection between research progress and the cultivation of human resources grew more tenuous.[42]

Consequently, many research agencies see a larger need for funding undergraduate teaching directly. In addition, many faculty have proposed novel ideas. For example:

> What if the four-year colleges. . . began requiring the university departments whose doctoral students apply for jobs at the four-year colleges to provide a detailed description of how they had prepared those candidates to teach, as well as specific evaluations of their teaching skills? . . . Granted, the most selective graduate departments at the top research universities-those that aspire chiefly to staff the faculties of" other prestigious universities-might not be especially responsive. . . . Although institutions routinely "raid" each other for distinguished researchers, they hardly ever pursue outstanding teachers so aggressively. As long as that disparity exists, talented teachers will be captives of their current employers, with little leverage to extract greater rewards.[43]

Indeed, growth in the employment of Ph.D.s by 4-year institutions has been hearty for over a decade.[44]

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[41] Of particular concern is its effect on the recruitment of new baccalaureates, since they may have to wait until their sophomore or junior year until they are taught primarily by faculty. The utilization of graduate students for teaching posts, however, can be quite valuable from the graduate student's prospective, since these classes may represent one of the few opportunities to teach (though not necessarily *learn how* to teach). In 1990, the Howard Hughes Medical Institute announced a $30 million grant competition to strengthen undergraduate science education. Ninety-nine institutions, many of them liberal arts colleges, will compete for 5-year grants ranging from $500,000 to $2 million. Winners will be chosen on the basis of proven success: the proportion and number of graduates who, over the past decade, have gone on to medical school or to earn doctorates in biology, chemistry, physics, or mathematics. For background, see Liz McMillen, "Hughes Institute Awards $61 Million for Science Education,'' *The Chronicle of Higher Education, vol. 35, No. 38,* May *31,* 1989, pp. A19-A20; and Linda Marsa, ''Howard Hughes Medical Institute Enriches Undergrad Science Studies," *The Scientist,* vol. *5, No.* 1, Jan. *7, 1991, pp. 28-29.*

[42] See Anthony B. Maddox and Renee P. Smith-Maddox, "Developing Graduate School Awareness for Engineering and Science: A Model, " *Journal of Negro Education,* vol. *59,* 1990, pp. 479-490. This connection has also arisen over requiring institutions of higher education receiving Federal assistance to provide certain information on graduation rates, broken down by program and field of study. See Public Law 101-542, Title I-Student Right-To-Know, 101st Cong., Nov. 8, 1990, 104 Stat. 2381-2384.

[43] Teaching reputations are local, while research reputations are global. This applies even to prospective students. The best students tend to flock to institutions where faculty have the greatest external reputations. Richard Chait, ''The Pro-Teaching Movement Should Try Economic Pressures,"*The Chronicle of Higher Education, vol. 36, No. 43,* July 11, 1990, p. A36.

[44] From 1975 t. 1987, percentage increases in the employment of Ph.D. scientists and engineers in 4-year institutions ranged from 15 percent in mathematics to over 200 percent in computer science (albeit from a small base number in this field). Most fields increased by 25 to 50 percent. For a discussion of these trends (based on National Science Foundation (NSF) data), see Commission on Professionals in Science and Technology, op. cit., footnote 5, pp. 18-19. The role of research at these traditionally *teaching institutions* is also cause for concern. In fiscal year 1988, of 21,000 research proposals submitted to NSF for funding, 12 percent cam from investigators at ''predominantly undergraduate institutions' and 8 percent of all awards were made to these investigators, accounting for 5 percent of NSF funds awarded competitively that year. See National Science Foundation *FY 1988 Research Proposal and Award Activities by Predominantly Undergraduate Institutions,* NSF 90-36 (Washington, DC: March 1990), p. 3. Also see Linda E. Parker and David L. Clark, ''Research at Liberal Arts Colleges: Is More Really Better?" *Research Management Review, vol. 3,* spring 1989, pp. 43-55.

These calls for increased undergraduate teaching by faculty seek to alter an academic research and teaching model in the United States that may already be under strain. What follows is an examination of the academic research model and its contribution to human resources at the Ph.D. level.

The Academic Research Model

The predominant mode of academic research in the natural sciences and engineering begins with a research group that includes a principal investigator (most often a faculty member), a number of graduate students, one or several postdoctoral scientists, technicians, and perhaps an additional nonfaculty Ph.D. researcher. While this group may be working on a single problem funded by one or two grants, subsets of the group may work on different but related problems funded simultaneously by multiple project grants. (In the social sciences, the groups tend to be smaller, often numbering only the faculty member and one to two graduate students.)[45] The ''young investigator' problem must thus be seen in the broader context of other changes in the university as a research training site.

During graduate study, along with self-teaching and learning from one's peers, much of what is learned comes directly through mentorship by professors, postdoctoral fellows, or nonfaculty researchers. In many research universities, professors are responsible for multiple graduate students at any given time, so that in a professor's career he or she may train over 20 (sometimes many more) Ph.D.s. As one observer commented:

> Simple arithmetic shows that training in a top laboratory at a top institution, combined with the requisite number of high-quality publications, does not by itself ensure anyone a position similar to that of his or her mentor. Most top laboratories graduate two or three postdoctoral fellows a year. . . . Multiply that by the large number of top laboratories in the country, and it becomes clear that even in good times not all these young investigators and their research programs can be absorbed into the National Institutes of Health system.[46]

Photo credit: Chuck Painter, News and Publications Service, Stanford University

Graduate students work in the Center for Integrated Studies at Stanford University. Research and teaching go hand-in-hand in much of graduate training.

In addition, the dominant model to launch a career as a young scientist is movement from one research university to another with an assistant professorship, the attainment of a first Federal research grant, and the re-creation of the mentor's professional lifestyle (i.e., independent laboratory, graduate students, postdoctorates). For an institution to subscribe to this model, unfortunately shifts much responsibility for awarding tenure from the department faculty to the Federal Government. While university officials say there is ''. . . no fixed time in which researchers are expected to become self-sufficient through outside grants . . . researchers who have failed to

[45] The exploitation of competent graduate students has been a perennial charge-some mentors keep them around as long as possible because they are talented cheap labor. Competition for tenure-track positions requires refereed publications on the resume of the new Ph.D. This, too, may prolong the graduate research career. Registered time to the doctorate increased from 1%7 to 1986, yet a recent National Research Council study suggests that the reasons for this increase cannot be readily deciphered. According to one observer, the recent leveling off of this trend in time to Ph.D. may reflect ''. . . changes in the job market for new Ph.D. recipients. It will be interesting . . . to see if the numbers fall-as market-oriented theories would predict—when the expected increase in demand for faculty begins later in the 1990s.' See National Research Council, *On Time to the Doctorate: A Study of the Increased Time to Complete Doctorates in Science and Engineering (Washington DC:* National Academy Press, 1990); Peter Syverson, "NRC Releases New Study on Increased Time to the Doctorate," *CGS Communicator,* vol. 23, August 1990, p. 8; and Paul Gassman, "Shortening the Time to a Ph.D.," *Chemical & Engineering News, vol. 68, No. 52,* Dec. 24, 1990, pp. 25-26.

[46] Dinah K. Bodkin, ''Young Scientists and the Future,' letter, *Science,* vol. *249,* Sept. *28, 1990,* pp. 1485-1486. Of course, some of these Ph.D.s will neither pursue an academic career nor compete for National Institutes of Health funds. The situation is less predictable than the author's extrapolation suggests.

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Box 7-C—Point of View of a "Small" Scientist

The following are verbatim excerpts from a recent "Point of View" column titled: "We Need To Give a Chance to Small, Unfashionable Science,' published in *The Chronicle of Higher Education.*[1]

> While literally millions of dollars are being spent on massive, equipment-rich projects, other 'small' sciences are in real danger of drowning for lack of funds. . . . Although I've received 22 grants from the National Science Foundation and a host of private foundations during the last 15 years, grant money is now much harder to get. Support for anthropology has gone from modest to minuscule.
>
> "There's no real problem, ' I used to think while responding sympathetically to my peers' groans over another rejected grant. ''Good science will always get funded. ' 1 learned this magic formula from my mentors while I was in graduate school and thought that if I repeated it often enough and believed it devoutly enough, I would be protected from disaster. But plenty of good science is not receiving support these days. . . .
>
> ' 'The long-term trends are grim. In the last 10 years, the number of grant applications submitted annually to the National Science Foundation's anthropology program has risen, as have the indirect costs of research. But the total budget for the program has remained approximately constant in real dollars, Consequently, the percentage of applications receiving support has dropped. For example, 32 per cent of the applications submitted for archaeology research in 1980 were approved, compared with only 23 per cent in fiscal 1990. What's more, the average dollar amount of the grants has dwindled during a period when virtually all the costs of actually conducting research have risen. John Yellen, director of the foundation's anthropology program, said recently with a sigh: ''What seemed a large but reasonable grant for us to fund 10 years ago now looks out of sight". . . .
>
> ''I do not know where the next generation of field researchers will come from, because the odds against starting up a major project are so great now. I do know that without field researchers, anthropology will stagnate into a family feud and eventually will perish from sheer triviality. . . .
>
> ' 'Some deliciously subtle ways exist for a reviewer to sabotage a grant proposal, thereby blocking or stalling a particular line of research, They range from simply giving a vaguely lukewarm review, to claiming falsely that the applicant has overlooked important work in the field, to planting poisonous questions about methodology that the review panel will then assume have not been addressed in the proposal. The temptation to engage in such unethical behavior is greater if everyone is feeling the pinch. . . . Under these conditions, the review process becomes one of paring down the proposals to a manageable number for ranking, rather than deciding how many are good enough to receive support. .
>
> ' 'The dilemma for program directors is: With too little money to go around, should they spread it around like food supplies in a famine, giving everyone enough for a taste but not enough to maintain health? Or should they support fewer projects more fully, condemning others to oblivion?
>
> ''I would love to see a box printed on federal income tax forms saying, "Check here if you want one dollar of your return to go to support basic science research." Another solution is to guard against spending all of our money for megabucks projects with catchy titles that appeal to legislators. Small, unfashionable science, as well as big, sexy science, is important. Sometimes great ideas and staggering discoveries come from the little guys with funny ideas, pottering away in the comer by themselves. We need to give them a chance. . . . "

[1] The author is Pat Shipman; the column appeared Sept. 26, 1990, p. A60. For another expression of related values, see Eugene Garfield, "Fast Science vs. Slow Science, Or Slow and Steady Wins the Race, ' The *Scientist,* vol, 4, No. 18, Sept. 17, 1990, p. 14.

win such grants are less likely to earn tenure than their colleagues who have found such support.' '[47] In many fields, young Ph.D. s and older ones as well are living out this scenario (see box 7-C).

As seen in the preceding chapter, most universities cannot afford to defray faculty research costs for very long, and the cost of supporting students has in part been transferred to the research budget.[48] The

[47] See Debra E. Blum, ''Younger Scientists Feel Big Pressure in Battle for Grants, " *The Chronicle of Higher Education, vol. 37, No. 4,* Sept. *26,190,* p. A16. As one researcher put it: "Leading universities should make their own decisions about who their faculty are going to be, and not leave it to the study sections of NIH. ' Quoted in David Wheeler, "Biomedical Researchers Seek New Sources of Aid for Young Scientists, ' *The Chronicle of Higher Education,* vol. 36, No. 42, July 5, 1990, p. A23.

[48] Research assistantships experienced the greatest increase as the support mechanism for science and engineering students from 1980 to 1988. See National Science Board, op. cit., footnote 4, figure 2-11, p. 58.

combined costs of set-up and operation alone (which for the typical chemistry or biomedical laboratory is on the order of $200,000 to $400,000)[49] have ballooned. The priority of this academic, individual investigator-based research model has become increasingly difficult for some institutions, fields, departments, and faculty mentors to maintain.

The Federal research system is presently trying to cope with growing demand for research monies, as measured by proposals submitted to the research agencies.[50] A potential shift of members of the research work force out of universities and into another sector, or into academic work that is not research-centered, can be recognized as normal labor market adjustment. Such movement would testify to the versatility and adaptability of Ph.D. researchers and to the Nation's ability to utilize their talents.[51]

Computer science is just such a case example. About 800 new Ph.D.s in this field are granted annually in North America, double that of a decade ago. The demand for new faculty has slowed, new departments are not being created, and existing departments are not expanding. Industrial and government computer research leaders asked:

> whether the current situation warranted concern i.e., is there a Ph.D. surplus, or are the supply and demand levels reasonably in balance). Reports of graduating Ph.D.s not finding the kind of academic positions they desired. . . [lead to] the suggestion that the expectations of these graduates need to be adjusted. Not every bright, new Ph.D. will find an academic position in a top-tier research university. Postdoctoral positions in computer science are becoming more common, and. . . graduates will need to look toward second-tier research universities as well as four-year colleges in order to fulfill their career objectives.[52]

There is doubtless a role for universities to play in the diversification of research careers of recent Ph.D.s.[53] New Ph.D.s find it difficult to entertain alternative opportunities if they have no experience with them. Thus, programs that offer a summer in a corporate laboratory or part of an academic year at a liberal arts college can help advanced graduate students visualize working in settings other than the university. Arrangements that link a historically Black college or university or liberal arts college to a research university or national laboratory stretch the resources and experience of both participating institutions.[54]

If the career prospects that new Ph.D.s confront are so different from what they were taught to expect and value, there can be a crisis of confidence. As one university administrator states:

> We are giving out mixed signals. Universities are competing intensely with one another to hire the best young Ph.D.s. On the other hand, the positions (at least in many fields of science) available to the average but quite capable Ph.D. are not very attractive. Moreover, many very good students are turned off when they see what the young faculty are up against.[55]

49 One report on set-up costs in chemistry at the University of Minnesota shows fourfold increases from 1979-80 to 1989-90. See Paul G. Gassman, "Future Supply and Demand in Academic Institutions," *Human Resources in Science and Technology: Improving U.S. Competitiveness*, Proceedings of a Policy Symposium for Government, Academia, and Industry, Mar. 15-16, 1990, Washington, DC, Betty Vetter and Eleanor Babco (eds.) (Washington DC: Commission on Professionals in Science and Technology, 1990), pp. 35-36.

50 See U.S. Congress, Office of Technology Assessment, "Proposal Pressure in the 1980s: An Indicator of Stress on the Federal Research System," staff paper of the Science, Education, and Transportation Program, April 1990.

51 For a discussion see National Research Council, Office of Scientific and Engineering Personnel, *Fostering Flexibility in the Engineering Work Force* (Washington DC: National Academy Press, 1990). Among the National Research Council conclusions are: a) that the production of adaptable engineers is impeded not by the engineering curriculum, but how that curriculum is delivered; and b) that continuing education could enhance adaptability in the engineering work force.

52 John R. White, "president's Letter: Reflections on Snowbird," *Communications of the ACM*, vol. 33, September 1990, p. 19.

53 Better faculty advising of graduate students is an obvious need. See Carolyn J. Mooney, "The Dissertation Is Still a Valuable Requirement Survey Finds, But Graduate Students Say They Need Better Faculty Advising,' *The Chronicle of Higher Education, vol. 37, No. 18,* Jan. 16, 1991, pp. A15, A22; and Association of American Universities, *Institutional Policies to Improve Doctoral Education* (Washington, DC: November 1990).

54 To date, such arrangements have been most common in undergraduate engineering. One coalition, spearheaded by a 5-year, $15 million National Science Foundation grant, will establish a communications network for information dissemination, faculty exchange, workshops, and outreach to elementary, secondary, and community college students. The participating universities are City College of New York, Howard, Maryland, Massachusetts Institute of Technology, Morgan State, Pennsylvania State, and Washington. See "NSF Announces Multi-Million Dollar Grant To Form Engineering Education Coalitions," *NSF News*, Oct. 9, 1990. Also see Oak Ridge Associated Universities, *1990 Annual Report* (Oak Ridge, TN: 1990). Oak Ridge Associated Universities is a Department of Energy laboratory and a consortium of 59 colleges and universities engaged in research and educational programs in the areas of energy, health, and the environment.

55 Neal Lane, "Educational Challenges and opportunities," Vetter and Babco, op. cit., footnote 49, p. 94.

Universities are caught between the desire to train the next generation and the harsh reality that their research apprentices may face a different form of competition for resources (for a controversial example, see box 7-D).

New **Models**

The National Science Foundation recently announced that the 20 research universities that receive the most NSF support ". . . will work together to improve science and mathematics education in schools and to increase the number of women and minority students and faculty members in science and engineering. " Actions include changing tenure policies to reflect the extra family responsibilities often carried out by women and encouraging faculty to work with schoolchildren and teachers.[56]

Other models of education could be encouraged that feature a greater sharing of resources (e.g., equipment and space) and people (e.g., doctoral students, nonfaculty researchers, and technicians). Models that stress research in units other than academic departments, research in *nonacademic* sectors, and ***nonresearch*** roles in academia could be entertained. These models are already being applied in the centers programs sponsored by NSF. Centers, which support individual researchers (as faculty and mentors) as well, may represent a new way of doing business for NSF and the companies that participate in them.[57]

In the 1980s, centers at NSF became the focus of political dispute.[58] At issue was the appropriateness of promoting such a mode of research organization in view of the basic research and science education missions of NSF. For NSF, however, the centers complete ''. . . a balanced portfolio of individual investigator grants, facilities, and center activities. ' '[59] Engineering Research Centers (ERCs) were intended to foster university-industry collaborations. As a 1988 General Accounting Office study found, participating companies ". . . expect to benefit over time through better personnel recruiting . . . [even though] it is too early to determine the program's impact on engineering education. ' '[60]

Photo credit: U.S. Department of Energy

Three scientists work on a magnet for the Superconducting Super Collider. Teamwork is an important part of research groups.

[56]See ''NSF, Universities Plan for Women, Minorities, ' ' *The Chronicle of Higher Education, vol. 37, No.* 1, Sept. 5, 1990, p. A2. Incorporating incentives for affirmative action into programs that allocate research dollars underscores the importance of human resources as a criterion for Federal research funding, It remains to be seen whether universities respond--with or without prodding by the National Science Foundation.

[57]In 1990, the National Science Foundation (NSF) supported 19 Engineering Research Centers and 11 Science and Technology Research Centers (STCs) at $48 million and $27 million, respectively. Thus, together they account for less than 10 percent of NSF's budget, while providing a long-term funding base (5 to 11 years) for interdisciplinary and high-risk projects oriented to the applied, development, and commercial-use end of the research continuum, See Joseph Palca and Eliot Marshall, ''Bloch Leaves NSF in Mainstream,'' *Science, vol. 249,* Aug. 24, 1990, p. 850. In the block-gran~ multi-investigator approach embodied by STCs, ''NSF has rolled the dice on an experiment in science, and it will take some time to know whether it has come up with a winner. " See Joseph Palca, "NSF Centers Rise Above the Storm,'' *Science, vol. 251,* Jan. *4,* 1991, pp. 19-22, quote from p. 22. Also see Jeffrey Mervis, "NSF Cuts Back on Faltering Science, Technology Centers, ' *The Scientist,* vol. *5, No. 3,* Feb. 4, 1991, pp. 1,4, 24.

[58]See Robert L. Park, ''The Next Leader of the National Science Foundation Must Press for a Greater U.S. Investment in Science, " The Chronicle *of Higher Education,* vol. *36, No. 48,* Aug. 15, 1990, p. B3.

[59]John A. White, "Disputing Some Claims About the NSF," *The Chronicle of Higher Education,* vol. *37, No. 3,* Sept. 19, 1990, p. B4.

[60]The General Accounting Office adds that ". . . although cross-disciplinary and joint research are the goals of the ERC program, industry participants believe that the quality and type of research are more important reasons for sponsoring ERCS." See U.S. General Accounting Office, *Engineering Research Centers: NSF Program Management and Industry Sponsorship,* GAO/RCED-88-177 *(Washington DC:* August 1988), pp. 2-3.

Box 7-D—The Priority of Research Training

In November 1990, the Institute of Medicine (IOM) published a report on priorities in health sciences:

> The charge to the committee was to analyze the funding sources for research projects, training, facilities, and equipment by Federal and nonfederal sources. The committee was asked as well to develop a coordinated set of funding policies to restore balance among these components of the research enterprise in order to ensure optimal use of research dollars. . . . The goal of the study was to ensure that, at any given level of support, allocation policies would enable the scientific community to utilize available resources in the most cfficient manner so as to create an optimal research environment and achieve society's goals for research into human disease.[1]

First, by adopting "imbalance" as a premise and then by concluding that if the National Institutes of Health budget were not to grow over inflation in the coming decade (one of four funding scenarios considered by the IOM committee), expenditures for research training and facilities should take priority. The report rankled the biomedical research community. Leading the dissent was the Federation of American Societies for Experimental Biology (FASEB), which objects to any diversion of funds at the expense of individual investigators.[2]

FASEB rejected the premise of the IOM report that in an era of tight budgets, biomedical funds should be balanced. FASEB claimed there is no imbalance, arguing that increased funds for training and construction will jeopardize ". , . productivity in the foreseeable future. " FASEB president Thomas Edgington, an immunology professor at the Research Institute of Scripps Clinic, California, feared that implementation of the IOM recommendations would ". . . diminish advances of value to the public. " He continued: "We advocate. . . a total increase of support of the enterprise as a whole. ' So while committee chairman Bloom insisted: ' 'We're eating our seed corn," Edgington concluded: "Training has not decreased. " Chemist Ronald Breslow, a member of the IOM committee, added another point on the training issue:

> supporting training through research grants ties training too much to the success of the research advisor. Giving money to the student rather than the sponsor changes their relationship. Trainees can then work on their own projects rather than being a sort of employee. It's more encouraging to the student to be told ''You are a winner' rather than ' 'Just go beg for support. '

This public dispute highlights several points. First, it attests to the depth of anxiety that grips investigators in search of stable, multiyear research finding. Second, by entertaining a' 'no real growth' funding scenario, the IOM report puts into black-and-white what few investigators want to contemplate, i.e., tight funding could get tighter. Third, by favoring an increase of research training funds under the worst-case scenario, the committee removed research funds as the first priority. Indeed, ''The committee believes that this growth in the training budget will not enlarge the research project grant applicant pool; rather, the net effect of this gradual reallocation will be to replace the increasing number of scientists expected to retire later this decade. '"[4]

This IOM report should be applauded for attempting to make forecasts and preparing for its consequences by systematically considering priorities among resources. However, the conclusion to increase training funds is problematic. [5]At present the system is producing an abundance of new Ph.D.s in biomedical fields. Enhancing this production while holding the line on the research grants that must support them is rightly open to question. Nevertheless, policy makers will welcome the IOM report for its look at a hard, complex problem and its statement of priorities.

1Institute of Medicine, Committee on Policies for Allocating Health Sciences Research Funds, *Funding Health Sciences Research: A Strategy to Restore Balance,* F.E. Bloom and M.A. Randolph (eds.) (Washington, DC: National Academy Press, 1990), p. 5.

2The Federation of American Societies for Experimental Biology criticism was reported almost simultaneously by: Barbara J. Culliton, ''FASEB 'Rejects' IOM Study," Science, vol. 250, Nov. 30, 1990, p. 1199; ' 'Strife Erupts Over Shares of Biomedical Funding, " Science & *GovernmentReport.* vol. 20, No. 19, Dec. 1, 1990, pp. 14; and Pamela Zurer, "Biomedical Research: Calls for Shifts in Funding Attacked," *Chemical & Engineering News,* vol. 68, No. 49, Dec. 3, 1990, p. 6. Material quoted below comes from one or all of these sources.

3Also see Ronald Breslow, ''Funding Science Research,'' letter, *Chemical & Engineering News,* vol. 68, No. 51, Dec. 17, 1990, p. 2.

4See Institute of Medicine, op. Cit., footnote 1, p. 8. Also see National Research Council, *Biomedical and Behavioral Research Scientists: Their Training and Supply* (Washington, DC: National Academy Press, 1989).

5Edgington also assailed the makeup of the IOM Committee, saying that it was composed mostly of research administrators and had few working scientists.

Table 7-1—issues in Team Research Performed in Different Organizational Contexts

Key issues	Small, university based	Large, university based (organized research unit)	Small, industry-based	Large, industry based
Number of disciplines involved	small	Moderate	Moderate	Moderate to large
Typical research	Pure	Pure-applied	Applied-pure	Applied and pure-applied
Funding	Short term and uncertain	Relatively certain	By contract and short term	Relatively certain
Source of research problems to be solved	Found by team	Found by team (largely)	Given by environment	Found by team and given by environment
Structure of organization	flat	Hierarchical (selective decentralization)	Flat	Hierarchical (selective decentralization)
Leader's involvement	Part time	Full time	Part time	Full time
Member's career prospects	Uncertain	Relatively certain/ predictable	Uncertain	Relatively certain/ predictable
Key leadership roles	Outside liaison	Outside liaison and coordination	Outside liaison and resource acquisition	Motivation and management of different teams
Communication problems	Few potentially	Internal and external	External	Internal
Access to scientific and technical resources	Good	Good	Not SO good	Good if affordable

SOURCE: Adapted from Julie Thompson Klein, *Interdisciplinarity:* History, Theory, *and Practice* (Detroit, MI: Wayne State University Press, 1990), table 1, p. 124.

Research in general is becoming increasingly interdisciplinary, i.e., it requires the meshing of different specializations to advance a research area.[61] Academic departments house specialists by discipline whose research will be performed in units--centers, institutes, programs-that cut across the traditional departmental organization on campus. Such organized research units (ORUs) have a history on U.S. university campuses, but not as a dominant structure.[62] Klein writes:

> In the 1960s Federal legislation gave birth to several kinds of ORUs, including NASA space centers, water resource centers, and later, regional education laboratories. A number of ORUs are de *facto* independent of the university that gave birth to them, and Caltech's Jet Propulsion Laboratory is even larger than its ''nominal parent, ' Caltech.[63]

Team research, whether interdisciplinary or not, takes place in many organizational contexts, subject to various influences (for a summary, see table 7-l). While the disciplinary department still prevails, a wide range of organizational models are now employed by universities to manage and conduct research. The autonomy, formality, and permanence of these production units depend on adapting the demands of outside patronage to local custom and need, including the support and on-the-job research training of graduate students.

[61] For example, see A.L. Porter and D.E. Chubin, ''An Indicator of Cross-Disciplinary Research, " *Scientometrics*, vol. 8, 1985, pp. 161-176; and Don E. Kash, "Crossing the Boundaries of Disciplines," *Engineering Education*, vol. 78, No. 10, November 1988, pp. 93-98.

[62] D.I. Phillips and B.P.S. Shen (eds.), *Research in the Age of the Steady-State University* (Boulder, CO: Westview Press, 1982). Three models of organized research units (which are common in industry and the Federal laboratories) have taken root on campus-agricultural experiment stations, water resources research centers, and engineering research centers. See Robert S. Friedman and Renee C. Friedman, ''Science American Style: Three Cases in Academy," *Policy Studies Journal*, vol. 17, No. 1, fall 1988, pp. 43-61. Several other models could be mentioned; e.g., the Joint Center for Laboratory Astrophysics at the University of Colorado, the Center for Astrophysics (the Smithsonian Astrophysical Observatory-Harvard Astronomy Department Partnership), and the Materials Research Laboratories (supported by the National Science Foundation).

[63] Julie Thompson Klein, *Interdisciplinarity: History, Theory, and Practice* (Detroit, MI: Wayne State University Press, 1990), P. 123.

[64] See Donald Pelz and Frank D. Andrews, *Scientists in Organizations: Productive Climates for Research and Development*, revised ed. (Ann Arbor, MI: University of Michigan, Institute for Social Research, 1976).

Box 7-E—Flexibility at the Beckman Institute

The Beckman Institute for Advanced Science and Technology is located on the University of Illinois Urbana-Champaign campus and was built with a 1985 donation of $40 million from Arnold and Mabel Beckman. In the words of its director, Theodore L. Brown, the mission of the institute is . . to advance the life and behavioral sciences, physical sciences, and engineering through promotion of multidisciplinary and interdisciplinary research of the highest quality, " in particular".. . to transcend the limitations of departmental structure."[1] 0ver 700 faculty, postdoctoral associates, graduate students, and others work full- or part-time at the institute.

The institute divides its research programs into nine multidisciplinary groups. For example, one group includes faculty in neuronal pattern analysis, cognitive neuroscience, perception, biomechanics, and molecular biology. It addresses a range of problems from the molecular level to cognitive science.[2] Perhaps most well known of the nine groups is the National Center for Supercomputing Analysis, which performs research in the diverse use and analysis of supercomputer-generated models.

To maintain flexibility in its research missions and yet provide some measure of security for the faculty, the Beckman Institute has taken advantage of its position outside of the university departments and developed a' 'rolling appointment' system:[3]

- Roughly 35 faculty call the Beckman Institute their full-time research home, although each retains a departmental affiliation. Faculty have 5-year appointments, which are extended every year, as long as their research is productive for the institute. If the appointment is not extended, then the faculty member has 5 years in which to move back to his or her department (where their tenure is based).
- Another 90 to 100 faculty members are part time at the institute, and are based primarily in their departmental homes. Each has a 3-year appointment, which is renewed like appointments of full-time faculty.
- Space is allocated in the institute only for those who use it, and is taken away if insufficiently occupied.

So far the system has worked well for the faculty at the institute; it represents a novel attempt to maintain flexibility in the university environment. In the future, other institutes and centers may view the Beckman Institute as a model.

[1] See Ward Worthy, ' 'New Beckman Institute Promotes Broad-Ranging Researc h Effort," *Chemical & Engineering News*, vol. 68, No. 34, Aug. 20, 1990, pp. 23-24.

[2] Ibid., p. 23.

[3] Ibid., p. 24.

With the ascendance of what OTA called in the last chapter the ''industrial model' of research, changes in the units producing knowledge have become apparent.[65] One could predict that university investigators will gravitate to those units that bring together the needed personnel and instrumentation, and ease the research process, especially if Federal and other sources of support favor centers as efficient sites of research performance (see box 7-E). Does it matter that research laboratories in an academic department come to resemble an ORU—be it an ERC, a supercomputer center, or another campus-wide institute that is largely federally funded?[66] One physicist writes:

> Goal-oriented research and a traditional belief in team methods favor large, centralized approaches in many industrial and Federal laboratories. (Small groups can also flourish in these environments-the two discoverers of high-temperature superconductivity are industrial scientists.) . . . For the same reasons that artists use different environments or new media to stimulate creativity, scientists need different ways to do science. This will help ensure

[65] Science policy statesman John Ziman claims that science is ". . . being 'collectivized' in two different senses of the word. On the one hand, almost all research nowadays is being carried out within the framework of quite large organizations . . . In many cases, research projects are undertaken by groups or teams of researchers who have limited control over the resources they use, and cannot claim personal responsibility for what is attempted or what is achieved. In other words, the extreme *individualism* embodied in the academic ethos . . . is no longer consistent with the realities of scientific life, where collective action is now the rule. . .. On the other hand, the incorporation of academic science into an expanding 'R&D' system, drawing funds from the central government and private industry . . . [means] academic science is losing its place as an autonomous social segment with its own standards and goals, and is being brought under 'collective' control. Instead of being treated as an independent source of unpredictable social influences, it has come to be regarded as an instrument of deliberate societal action. ' See John Ziman, ''Collectivized Science, " *An Introduction to Science Studies* (Cambridge, England: Cambridge University Press, 1984), pp. 132-139, quote from pp. 138-139.

[66] See National Research Council, *The Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987).

that research careers attract good minds of every sort-those that flourish in isolation, and those that thrive on interaction.[67]

The trend toward larger research teams, more cooperation among individuals and groups, and more multiauthored papers is unmistakable.[68] The question is whether large research groups will effectively duplicate or augment the mentorship function. Whatever the campus research setting, it must be valuable for the socialization of new Ph.D.s. The ***process*** of scientific research is learned in university settings, but sometimes the skills associated with the process (e.g., data handling and communication practices) do not transfer well to nonacademic settings.[69]

Other Considerations

Federal research funding serves various goals, none more important than the strengthening of education and human resources. The Federal Government has a special role both as a primary catalyst of the future supply of Ph.D.s and as one employer of the existing Ph.D. work force.[70]

In addition to the issues outlined above, the Federal Government must also consider several questions. First, given the tendency of Federal funding to concentrate in a small set of universities, what efforts should be made to support other institutions? (Or is there an optimal mix?) Twenty percent of all authors of scientific papers produce 80 percent of the scientific literature.[71] Furthermore, basic researchers are concentrated in a relatively small subset of all academic institutions, and conventional wisdom says that scientific productivity depends on the extraordinary achievements of relatively few researchers, laboratories, and universities.[72] Writing in 1968 as a physicist and academic dean, as well as a policy advisor, Harvey Brooks put it this way:

> The vigor of a scientific field seems to depend on a continuing injection of new investigators with fresh ideas and on sufficient funds to exploit new ideas. . . . To spread the same funds more and more thinly over a growing number of investigators, institutions, and students would be a prescription for the slow strangulation of science in the United States.[73]

To avert the "slow strangulation of science," a concentration of funding in select research institutions and research groups (which is what the Federal Government currently practices) would seem wise. However, at what point does concentration begin to disrupt the interdependence among researchers? Not funding a wide array of researchers risks curbing more than the flow of resources; it can interrupt the flow of communications and begin to deter cooperation between specialists. Such cooperation, which contributes to the accumulation of research findings, is especially intense at universities.[74] Sustaining productive researchers (and the students who will eventually join the top ranks of scientists and engineers) fuses Federal research funding policy

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67Sidney Perkowitz, "Larger Machines Are Breeding Larger Research Teams," *The Scientist*, vol. 3, Oct. 16, 1989, pp. 13, 15.

68National Science Board, op. cit., footnote 4, p. 120.

69For a discussion, see National Academy of Sciences, Committee on the Conduct of Science, *On Being A Scientist* (Washington, DC: National Academy Press, 1989), pp. 10-22. Also see Terry Shinn, "Scientific Disciplines and Organizational Specificity: The Social and Cognitiv Configuration of Laboratory Activities,' *Scientific Establishments and Hierarchies, N.* Elias et al. (eds.) (Dordrecht, Holland: D. Reidel, 1982), pp. 239-264.

70The Federal Government employs 200,000 scientists and engineers, about 11 percent of the Federal work force. And although many of these people neither have a Ph.D. nor do bench research, they are facilitators of research performance (as agency program managers). Micromanagement of the Federal laboratories, personnel ceilings, noncompetitive salary, inadequate fringe benefits, ethics laws, and the public image of Federal service are reported to contribute potentially to a Federal "brain drain." Yet only 5 percent leave Federal employment annually. See Janice Long, "Agencies Compete Well in Science Job Market," *Chemical& Engineering News*, vol. 68, No. 39, Sept. 24, 1990, p. 23. For further discussion, see Alan K. Campbell and Linda S. Dix (eds.), National Research Council, *Recruitment, Retention, and Utilization of Federal Scientists and Engineers* (Washington, DC: National Academy Press, 1990).

71Jonathan R. Cole and Stephen Cole, "The Ortega Hypothesis," Science, vol. 178, Oct. 27, 1972, pp. 368-372. Also see Sharon Levin and Paula E. Stephan, "Research Productivity Over the Life Cycle: Evidence for Academic Scientists," *American Economic Review*, vol. 81, March 1991, pp. 114-132.

72See Gene Bylinsky, "America's Hot Young Scientists," *Fortune*, vol. 122, No. 9, Oct. 8, 1990, pp. 56-69. Also see David Pendlebury, "Science Leaders: Researchers to Watch in the Next Decade,' *The Scientist*, vo1. 4, May 28, 1990, pp. 18-19, 22-24; and A.L. Porter et al., "Citations and Scientific Progress: Comparing Bibliometric Measures With Scientist Judgments,' *Scientometrics*, vol. 13, 1988, pp. 103-124.

73Harvey Brooks, "The Future Growth of Academic Research: Criteria aud Needs," *Science Policy and the University*, Harold Orlans (cd.) (Washington, DC: The Brookings Institution@ 1%8), pp. 75-76.

74Researchers form informal networks according to their specialization in addition to the formal organizations in which they work. It is not known how changes in funding patterns affect informal as opposed to formal communication. See Leah Lievrouw, ' 'Four Research Programs in Scientific Communication" *Knowledge in Society*, vol. 1, summer 1988, pp. 6-22.

with training, employment, and productivity concerns.

A further aspect of concentration of funding, and one of mounting concern to universities and agencies alike, is the degree to which the Federal Government could promote participation in science by disadvantaged groups and by regions of the Nation that have not traditionally received large amounts of Federal research funds. Disadvantaged groups and potential scientists and engineers who are geographically dispersed in research are considered by many to be untapped resources that could enhance U.S. research capacity. At present, set-aside programs help to accomplish these goals (see box 7-F). A more concerted and sustained effort by the Federal Government to increase participation is warranted in the coming decade.

A final question is this: should the Federal Government focus its educational support on graduate fellowships, traineeships, and research assistantships (regardless of the combination), or spend a larger proportion of funds on undergraduate education and earlier segments of the pipeline? If one believes the projections of future shortages in Ph.D.s for the 1990s, then the Federal Government could produce many more Ph.D.s for the short term to meet the need, and then reconsider the question. If there are concerns about these projections (as OTA has ascertained), then the Federal Government could take a long-term view and work to enhance the supply throughout the pipeline. This would particularly argue for a greater investment in undergraduate science and K-12 education. As labor economist Alan Fechter writes:

> The relevant policy issue should be whether the expected equilibration mechanisms triggered to correct . . . imbalances will be consistent with national needs and more global social objectives. . . . If not, then policymakers will need to consider other mechanisms that will equilibrate supply and demand with minimal unwanted side effects.[75]

A key concern for the future of the research work force is not only the size of the pipeline, but the *composition* of the students in it. What is the relative proportion, especially at the doctoral level, of U.S. citizens and foreign nationals? The evidence presented in this chapter on the chronic underrepresentation of women, minorities, and the disabled among science and engineering Ph.D.s suggests that financial support mechanisms have discouraged certain segments of the talent pool from pursuing graduate study. How can the Federal Government, through direct financial incentives and institutional programs that can modify student aspirations, reverse this trend? The answers have implications not only for the size of the work force, but also for the character of the scientific work that new participation automatically brings to the Nation's research enterprise.[76]

Photo credit: University of Washington

A student in the Early Entrance Program at the University of Washington performs a physics experiment. Science education from K-12 through undergraduate levels is vital for preparing the science and engineering research work force.

Conclusions

The U.S. system of doctoral production has consistently displayed its excellence over the past 40 years. The number of doctoral scientists and engineers employed in the United States has grown by almost 50 percent since 1977. Nevertheless, several trends in the production of new Ph.D.s are of concern. Many also question whether shortages in the future U.S. scientific and engineering work force, and particularly its research component, are inevitable.

[75]Fechter, op. cit., footnote 26, p. 19. Also see Lisa Simon, "Despite Scientist Shortage, Future Ph.D.s Fear Joblessness," *The Scientist*, vol. 5, No. 1, Jan. 7, 1991, pp. 24, 32.

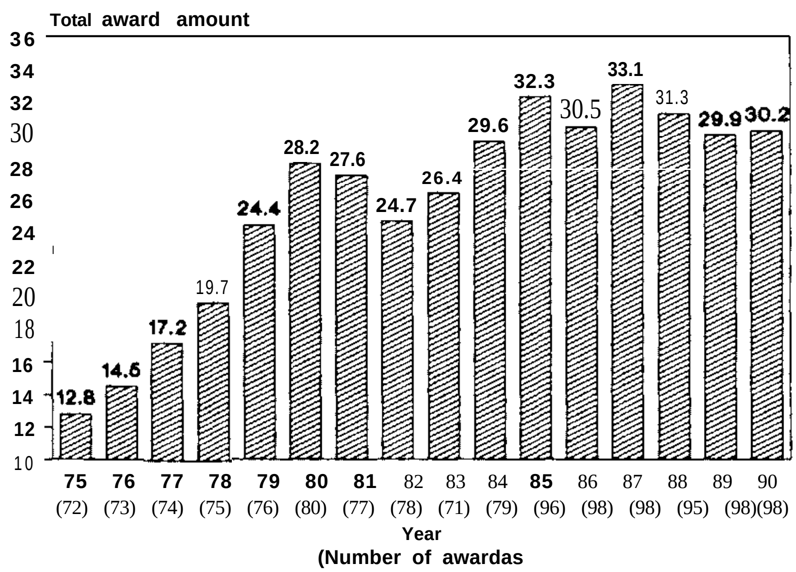
[76]For example, see Jerry Gaston, "The Benefits of Black Participation in Science," *Blacks, Science, and American Education*, Willie Pearson, Jr., and H. Kenneth Bechtel (eds.) (New Brunswick, NJ: Rutgers University Press, 1989), pp. 123-152.

Box 7-F—Minority Biomedical Research Support Program

As part of the National Institutes of Health's (NIH) effort to promote involvement of minority scientists in ongoing research, the Minority Biomedical Research Support (MBRS) Program awards grants to institutions with substantial minority enrollments. The purpose of the program is to support research by American Indian, Black, Hispanic, Native Alaskan, Asian, and Native Pacific Islander faculty and students in the biomedical sciences, and to strengthen the grantee institutions' biomedical research capabilities.[1]

Initiated in 1972, the MBRS Program was originally administered through the NIH Division of Research Resources, but in 1989 was moved to the National Institute of General Medical Sciences (NIGMS). Two- and four-year colleges, universities, and health professional schools with either 50 percent or more minority student enrollment or those with a demonstrated commitment to the assistance of minority students and faculty are eligible to apply for a project grant. The average annual grant is $350,(X)0, the highest $1.5 million. MBRS program grants may be used to support time for faculty members to engage in research; exploratory research and full-scale research activities through the purchase of equipment, supplies, and technical assistance; and undergraduate and graduate students working ''hands on " in a faculty member's research. Figure 7F-1 shows the size and number of MBRS awards for the past 15 years.

Figure 7F-1--MBRS Awards and Funding: Fiscal Years 1975-90 **(In millions of 1982 dollars)**



NOTE: MBRS - Minority Biomedical Research Support.

SOURCE: National Institute of General Medical Sciences, unpublished data, August 1990.

Project review and management, including monitoring progress and negotiating budgets, are assumed by NIGMS. As a line item in the appropriation for NIGMS, the MBRS Program received over $28 million in fiscal year 1989. The program received an additional$11 million from other NIH components (which have contributed

[1] What follows is based on National Institute of General Medical Sciences, ' 'Minority Biomedical Research Support Program+' administrative document, April 1990.

There are pitfalls in many of the methodologies employed in Ph.D. projections: their track record is troublesome. Most notably, OTA questions the ability of statistical analyses to predict future demand for Ph.D.s, especially when coupled with uncertainty about levels of Federal and industrial support for s/e research in the 1990s. Nevertheless, these trends should be monitored, and investments in the educational pipeline continued to ensure a robust supply of students. This is in the national interest, not just essential for science, engineering, and the research enterprise. For this reason alone, increasing the attention to teaching in research centers is warranted.

for the past 13 years) to help support MBRS research projects of direct relevance to their own missions. Presently, 11 other NIH components and the Alcohol, Drug Abuse, and Mental Health Administration co-fund MBRS projects.

The MBRS Program has two funding mechanisms. The first, the traditional MBRS Program, provides support of up to $1.5 million per year for faculty members to carry out research projects. To be eligible, an institution must undertake at least 2 and no more than 25 research projects and must involve at least 2 faculty members having different research interests. A heavy emphasis is placed on involvement of undergraduate and graduate students in faculty research projects. The hope is that from this interactive relationship, a commitment to science will develop, and biomedical research will become an attractive career option for those students. While faculty members are expected to submit their work for publication in peer-reviewed scientific journals, the program also expects students to participate actively in the research, coauthor publications, attend scientific meetings, and give presentations.

The second component of the MBRS Program, the Program for Undergraduate Colleges and Two-Year Colleges, began in 1985 and supports enrichment activities, pilot research projects, and regular research projects. The maximum award under this program is $450,000 in direct costs over 3 years, plus indirect costs. A portion of these award monies must be applied toward "enrichment activities," such as workshops, attendance at scientific meetings, and summer research experiences in off-campus laboratories. In addition to the two primary award programs, the MBRS Program started supplemental funding for both instrumentation and animal resource improvement in 1983 and 1987, respectively.

Currently, institutions in 31 States are supported by the MBRS Program, with California and Puerto Rico having the most institutions participating in the program (nine and eight, respectively). Like many programs targeted to groups underparticipating in science, the MBRS Program represents a well-institutionalized model that could be generalized if funding permitted. As a recruitment and retention device, the program couples students to role models, previews science as a career, and builds institutional capability to compete for Federal funds and conduct collaborative, cutting-edge research. A significant number of awards are concentrated in southern States with large minority populations, such as Alabama, Georgia, and Tennessee. Thus, the MBRS Program, in conjunction with the other NIH efforts, is intended to produce a larger minority presence in the research work force.

While OTA has presented data on human resources in research, more detailed data could be collected. For instance, it is at best possible only to estimate, with presently available data, the size of the *research* work force. Based on the NSF estimates cited above, the U.S. s/e work force of academic Ph.D.s totals 340,000; those reporting research as a primary or secondary work activity total 155,000. So less than one-half (about 45 percent) of those in the academic sector are engaged at all in research, but this represents an unknown fraction of the total research work force. The proportions federally funded and the number of scientists and engineers leaving research careers are also unknown. Even less information exists on the evolution of research groups (and its effect on graduate training). Much anecdotal evidence and some personnel expenditure data from NIH and NSF indicate that research groups are becoming larger on average, yet the size of the distribution and its rate of growth are unknown. (The next chapter reviews the state of data on the research system, and presents suggestions for enhanced data collection in the Federal agencies and elsewhere.)

Based on the trends reviewed here, OTA finds that there is no current crisis in the Nation's ability to do scientific research. The Federal Government may wish to do nothing now to intervene in the Ph.D. production system and let market forces operate unencumbered. Federal funding will continue to serve the goal of excellence in research. If funding growth slows, however, the related goals of education and human resources risk becoming second-order priorities. All markets would be fortified by enhancing the education pipeline, especially at the undergraduate level, to ensure that future shortages can be met.

However, the composition of students in the pipeline-by gender, race/ethnicity, and nationality-is of greater concern. The scientific community could benefit from the diversity of research interests and approaches that new entrants bring, especially those from groups who have historically not participated fully in it. The Federal Government may also wish to consider, through new legislation, more extensive and long-term support for the recruitment of potential scientists and engineers from groups disadvantaged within s/e, as noted above. A diversity of personnel and career paths will distinguish the research work force of the 1990s.

Policies could be devised that target incentives for s/e labor markets disaggregated by field and sector. Research in many fields is moving toward a more "industrial" model, with larger teams, specialized responsibilities, and the sharing of infrastructure. In response, the Federal Government has acknowledged changes in the (sometimes interdisciplinary) composition and more complex structure of research groups through centers and block-grant funding. Perhaps it should now provide the impetus for universities to examine and experiment with their policies concerning the opportunities and rewards for nonprincipal investigators, e.g., postdoctorates and nontenure track researchers.

All policy initiatives will need to consider impacts on undergraduate and graduate teaching, the stress on the current academic model of research and education, and new models that might lessen institutional strain. Reauthorization of the Higher Education Act of 1965 by the 102d Congress will provide an opportunity to encourage universities to increase the rewards for undergraduate teaching and enhance undergraduate and graduate experience in diverse career paths. If this chapter has demonstrated anything, it is that human resources are a main business of the Federal Government, and not a marginal concern in strengthening the Nation's scientific research capability.