Chapter 3

Graduate Education and the University

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The United States has a globally respected tradition of graduate student as research apprentice, intimately linking research and education. The graduate student earns an advanced degree by acquiring specialized knowledge, research skills, and experience working in the laboratory with a faculty mentor.

The centerpiece of basic research training in the United States is the research university, the public and private institutions that grant most science and engineering Ph.D.s and receive the lion's share of Federal and non-Federal academic research and development (R&D) funds.[1] The top 100 research universities represent less than 3 percent of all U.S. institutions of higher education but about one-third of all science and engineering Ph.D.-granting universities. Collectively, they receive 82 percent of Federal academic science and engineering obligations and house nearly two-thirds of full-time science and engineering graduate students.[2]

The resources and capabilities concentrated in these universities have been the mainstay of basic research and graduate education in the United States. Interest in the health of the national research work force and the universities themselves gives the Federal Government a twofold interest in graduate education at universities. David Hamburg cautions about considering the universities too narrowly as a 'manpower machine" for producing scientists and engineers for specific needs: "I would urge taking a broader view of the 'state of health' of the national science and technology enterprise of which academic R&D is a unique and vital part."[3]

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1. "Science and engineering includes the social sciences as well as the physical and biological sciences, mathematical and computer sciences, and engineering.
2. The top 100 research universities are defined here in terms of amount of Federal R&D funds received. This group correlates well with 'high-quality" universities as determined by surveys of scientists and academics. See National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year: 1986,* NSF 87-318 (Washington, DC: 1987); U.S. Congress, General Accounting Office, *University Funding: Patterns of Distribution of Federal Research Funds to Universities,* RCED-87-67BR (Washington, DC: February 1987).
3. David A. Hamburg, Carnegie Foundation, testimony before the U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, July 9, 1985, p. 13.

WHAT IS GRADUATE STUDY?

College gives students a basic education in fundamental science and engineering knowledge. Becoming an independent research worker demands the advanced specialized learning and hands-on apprenticeship of graduate study. Upon completion of the baccalaureate degree, the educational system offers science and engineering students two further degree goals: the master's and the doctorate. Both degrees are awarded following a term of apprenticeship in graduate school, but there is a considerable difference between them. The short course is the master's degree, usually 1 or 2 years of study, mostly in the classroom. The specialized knowledge of the master's recipient brings enhanced earning power and professional responsibility. The long course is the Ph.D., 4 to 6 (if not more) years of low-paid apprenticeship, which gives the survivor full professional standing.

The Master's Degree

The master's degree serves many purposes — professional credential, way station to the Ph.D., and consolation prize for leaving doctorate study.[4] The master's has long been an important final degree for many professions, including engineering and the applied sciences, but is a less significant credential for the research work force. Master's programs are usually focused more on practical knowledge than on research or academic enrichment. Over three times as many people receive science and engineering master's degrees each year as Ph.D.s (see figure 3-l). The master's is most valued in the applied sciences; engineering accounts for one-third of science and engineering master's recipients.

Most engineering schools have two tracks for their graduate degree programs. One track is for those wishing to do research; it is typically comprised of a l-year master's of science program, which leads into a Ph.D. program. The other track is the master's of engineering (M.E.), usually a 2-year program that may lead into a doctorate of engineering program. Both of the programs in this track are applications-oriented.[5]

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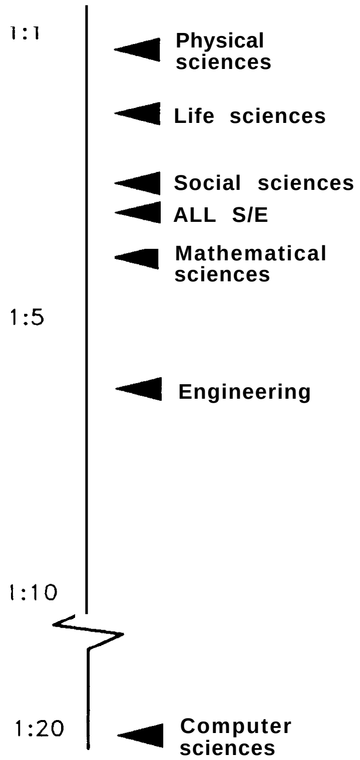
4. Judith S. Glazer, *The* Master's Degree: *Tradition, Diversity, Innovation,* ASHE-ERIC Higher Education Report No. 6 (Washington, DC: Association for the Study of Higher Education, 1986), p. xiii. Here the word 'master's' encompasses all first professional degrees.

5. Engineering disciplines, even within the same institution, differ in the value they accord the M.E. degree. At the University of California, Berkeley, for example, one-quarter of its civil engineering master's level students earn the M.E.; in mechanical

Figure 3-1. - Ph.D.-Master's Degree Ratio, by Field, 1986



Key: S/E = science/engineering.

SOURCE: Office of Technology Assessment, 1988, from National Science Foundation data.

The proportion of entering graduate students planning to complete the master's degree only is difficult to estimate, but it lies somewhere between 35 and 85 percent.[6] About 30 percent of graduate students are in departments that grant only master's. A few of these continue for Ph.D.s elsewhere. But many additional master's-planning students are in doctorate-granting departments, and many Ph.D. students will drop out with only a master's, so a higher proportion of all graduate students, perhaps as high as 65 percent, actually end up with a master's.

The attractiveness of a master's degree in science or engineering varies with the demand and supply of those with higher credentials. In fields with generous supplies of Ph.D.s, as in most life sciences, the holder of a master's degree may work as a laboratory technician. (There are differences, however, by employment sector as well as field: in industry, the M.S. scientist is frequently a fully independent researcher.) A robust job market is likely to lure students away from school with only a master's degree and to discourage students from continuing to the doctorate.

The doctorate, however, is a sine qua non for an academic faculty or research post, and increasingly important for professional research positions in industry. This chapter focuses on students pursuing the doctorate.

Doctoral Study

Doctoral programs in science and engineering are not only the final formal stage of education, but also initiation into the research community. Doctoral study in the sciences or engineering usually takes 4 or more years (assuming the student does **not** already have a relevant master's degree). The first year or two is often spent in advanced classes, and preparing for oral and written qualifying examinations that most universities require new graduate students to pass before they can continue their studies. The beginning graduate student often also teaches undergraduates as a teaching assistant, or may do research. Some entering students have already arranged to work

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engineering, this proportion is only 10 percent; and the Department of Electrical Engineering awards barely 1 or 2 a year (Pamela Atkinson, University of California, Berkeley, personal communication, November 1988).

6. Information is not regularly collected on "Ph.D. candidates. " Rather, the National Science Foundation collects data on all graduate students by part-time and full-time status, and by whether they are in doctorate-granting or master' s-granting institutions. About 60 percent of science and engineering graduate students are attending full time in institutions that grant Ph.D.s. Few research Ph.D.s come from outside this core population.

with a certain faculty member, and may have a research agenda planned out. Most new graduate students, however, spend no more than a year learning about various research activities at their university.

The choice of a research project and thesis advisor depends on a constellation of factors: what positions are available in various laboratories, the student's interest, funding opportunities, a mentor's perceptions of what constitutes a significant research problem (i.e., potential thesis topic), and luck (timing and serendipity). Postdoctoral students are doing research nearly full-time after a few years. The graduate student is not only a scientist in training, but a productive researchers well. The uncertainty of basic research means that research projects change during the course of thesis research. To earn a Ph. D., the graduate student must make a significant contribution to knowledge in his or her field, complete a written thesis, and pass an oral examination.

The U.S. model is not the only model. Appendix C discusses approaches by other nations to graduate study. Those few who embark on doctoral study in the United States are highly selected. The average quality of science and engineering graduate students is higher than that of baccalaureates, and no evidence suggests any substantial decline.[7]

THE MARKETS FOR PH.D.s

Graduate students respond to two different science and engineering labor markets: a "Pregraduate" market for university teaching and research assistants, and a dominant "postgraduate" market for academic and other research scientists and engineers. Federal policies and programs affect both of these markets.[8]

7. This conclusion is based both on qualitative assessments and test scores. Office of Technology Assessment data, 1987; National Commission on Student Financial Assistance, *Signs of Trouble and Erosion: A Report on Graduate Education in America* (Washington, DC: 1983), pp. 73-74; and Thomas Hilton, Trends *in* the *GRE* Scores Reported *to* the *NSF and to Selected Graduate Schools: 1974-1980* (Princeton, NJ: Educational Testing Service, January 1982). Several recent studies are reviewed in Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need to Know* (Washington, DC: Association of American Universities, 1986), pp. 40-44.

8. This section on pregraduate and postgraduate markets is paraphrased from Robert G. Snyder, "The Effectiveness of Federal Graduate Education Policy and programs in Promoting an Adequate Supply of Scientific Personnel, " OTA contractor report, June 1985, p. 4. A third, conscience and engineering market would be that for baccalaureates who seek MBA or law degrees.

Graduate education has a long history of "work-study" in the form of research and teaching assistantships. This serves the dual purposes of providing training in research and teaching and at the same time assisting faculty in their research and teaching responsibilities. The demand for graduate student enrollments increases as undergraduate enrollments rise or academic R&D support increases. By funding academic research, the Federal Government affects demand for research assistants. Policies that change college enrollments also change the demand for undergraduate (and graduate) teaching, and thus the demand for graduate teaching assistants.

The postgraduate market for doctorates in some respects resembles the traditional market for other occupations— as the economy and research enterprise expand, increased job openings and higher salaries attract more students and produce more graduates. Two key dissimilarities, however, exist — the time lag created by protracted educational preparation and the strongly academic market.

The time lag needed to attain a doctorate is considerably longer than for most occupations. Not only is a college degree needed, but 4 to 8 years of doctoral study. (And in some fields, the professional career is not launched with receipt of the doctorate, but after 2 to 3 years of postdoctoral study.) Hence, the market response is very long, which brings with it significant, and sometimes disruptive, oscillations between shortages and surpluses.

A second distinctive feature of the market for doctorates is its dependence on employment in academia itself. Academia is a nontraditional market in its use of tenure and its emphasis on externally-funded research, both of which provide stability and insulation from some, though certainly not all, economic incentives that drive other labor markets. Many Ph.D.s who plan an academic career also accept a temporary postdoctoral research appointment following their degree (in 1987, about one-third of science and engineering Ph.D.s, mostly in the life sciences). This is often a valuable time for new Ph.D.s to immerse themselves in research, free from teaching responsibilities, and prove themselves as full-fledged independent researchers. The postdoctorate is also a labor market buffer, a holding tank for young researchers during a tight market with few tenure-track academic posts and plentiful research dollars.

The level of Federal academic research funding, and the distribution of that funding among fields and research problems, affect both the pregraduate and postgraduate markets. Overall Federal R&D support influences the postgraduate employment outlook for both academic and nonacademic sectors. In addition, Federal policies affecting the economy, e.g., tax policy relating to high-technology industry or industry R&D, also influence the relative growth of employment for doctorates in the private sectors.

The Transition From College to Graduate Study

The transition from college to graduate school dilutes the science and engineering pipeline. Only a few percent of science and engineering baccalaureates continue on for further study.[9] A minority of these enter Ph.D. programs.[10] There are two complementary ways to enhance the supply of Ph.D.s: one is to increase the number of students entering graduate study, the second is to reduce attrition among graduate students and increase the proportion that attain Ph.D.s. Because the Ph.D. population is so small, any small increase in the proportion of college graduates who go on to graduate study would significantly increase the number of Ph.D.s. From the standpoint of the supply of scientists, the most pertinent programs are those that not only encourage graduate school attendance, but also foster graduate study through completion of the Ph.D. Programs to affect Ph.D. productivity must target students contemplating and entering graduate study as well as those already enrolled in graduate school.

Research is still considered by many to be a calling, with modest pay a financial sacrifice that is compensated by other attractive aspects of the research lifestyle. The choice to undertake graduate study is driven by students' career aspirations, their academic performance and confidence, perceptions of the size and stability of the salaries and demand for Ph.D.s, willingness to continue in school another 4 or more years, and the embedded influences of parents, mentors, and peers. One study suggests that natural science students have placed less importance on their financial futures, and worried less about current financial concerns, in their decisions to pursue graduate study than engineering or conscience students.[11]

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9. National Science Foundation, *The Science and Engineering* Pipeline, PRA Report *87-2* (Washington, DC: April 1987), pp. 3-4 (based on U.S. Department of Education data from the National Longitudinal Survey and High School & Beyond survey).

10. And among the cadre to make this important transition are few members of racial and ethnic minorities. For a comparative perspective, by field and race/ethnicity, on the attenuation of talent at this crucial juncture and its implications for the teaching and research work force, see Shirley Vining Brown, *Minorities in the Graduate Education Pipeline: A Research Report of the Minority Graduate Education Project* (Princeton, NJ: Educational Testing Service, 1987), pp. 8-16.

11. Consortium on Financing Higher Education, *Beyond the Baccalaureate: A Study of Seniors' Post-College Plans at Selected Institutions, With Particular Focus on* the Effects

Nevertheless, when extensive money was available for graduate study and the academic job market was booming, a much greater proportion of B.S. graduates went on for Ph.D.s. Long-term concerns over anticipated earnings and stability of a research career may also affect students' decisions. Many observers also believe that the current generation of students, with higher and more widespread educational debt, may be more strongly deterred from graduate study than previous generations.[12] Although most graduate education is subsidized, especially at the major research universities, graduate study is still a financial struggle and sacrifice, even for students on the most generous fellowships (see box 3-A).

The importance of nonfinancial criteria also shows up in students' choice among Ph.D. programs. Once students have decided to go to graduate school and have been accepted, the research reputation of a department and its faculty as well as financial aid offered determines where they attend. Short-term financial considerations, including anticipated expenses and small differences in financial aid packages offered by different schools, are not decisive in influencing students' choice among graduate schools to which they have been accepted.[13]

During and immediately after the Vietnam War, several economic factors discouraged students from attending graduate school. The two most important were the reduction in stipend support (which increased reliance on loans and lengthened the time to degree, and thus increased foregone income); and a poor labor market, particularly in academia.[14] But graduate enrollments did not decline in the 1970s and 1980s as much as

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of Financial *Considerations on Graduate School Attendance* (Cambridge, MA: March 1983), pp. 17, *24;* and Jerry Davis, Pennsylvania Higher Education Agency, personal communication, April 1988. The small, nonrepresentative survey population was 4,409 seniors at eight Consortium on Financing Higher Education (COFHE) institutions, and 1,910 seniors at three public institutions. Two of the eight COFHE institutions were women's colleges, which skews the results away from a "national average."

12. Janet S. Hansen, "Student Loans: Are They Overburdening a Generation?" Report for the Joint Economic Committee of the U.S. Congress, mimeo, December 1986, pp. 35-37; and College Scholarship Service, Proceedings: *College* Scholarship Service Colloquium on Student Loan Counseling & *Debt* Management, Dec. 2-4, *1985* (New York, NY: College Entrance Examination Board, 1986).

13. Margaret E. Boeckmann and Alan L. Porter, "The Doctoral Dissertation in the Biosciences," *Bioscience,* vol. 32, No. 4, April 1982, p. 273.

14. David W. Breneman, Graduate School *Adjustments to the "New Depression" in Higher Education* (Washington, DC: National Board on Graduate Education, February 1975). It is important to remember throughout this discussion that selective service and the brooding presence of a military draft has had profound effects on educational aspirations and the realization of career plans.

expected, for several reasons: students attended graduate school to improve their chances in an uncertain job market, slowed but still rising undergraduate enrollments fueled continuing university demand for Ph.D.-trained faculty and for graduate students to help with teaching and research, more women attended, and many students attended either part time or for nonfinancial reasons, such as the desire to pursue a research career and an academic lifestyle.[15]

Attrition From Graduate Study

Those who embark on doctoral study are highly selected through the formal hurdles of undergraduate study — testing, admission to graduate school, the allocation of financial support, and the personal assessments of faculty who have taught and worked with students as undergraduates. However, attrition is still disturbingly high. Nearly one-half of science and engineering graduate students fail to complete their doctorates. Over the course of years, some find that they do not like research, or go to more financially or socially rewarding or secure work.[16] Some succumb to the rigor of a challenging course of study and research. And the time required to earn a Ph.D. ensures some attrition. Many of those who leave have the potential and interest to become scientists and are in that sense a "real" loss to the research work force (see table 3-1). Yet those who leave use their scientific training in other fields. Many who leave without Ph.D.s stay in the scientific work force as researchers or teachers.

Attrition is surprisingly unpredictable on the basis of typical measures of student quality.[17] It is clear that universities can moderate attrition, not only by helping provide financial support throughout graduate study, but in shaping the rest of the environment, from housing and child care through academic support and advice. Universities have different approaches to "producing the best." Some universities accept only a few graduate students and work hard to see them all through. Others take pride in "washing

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15. Synder, op. cit, footnote 8.
16. Penelope Jacks et al., "The ABCS of ABDs: A Study of Incomplete Doctorates, 't *Improving College and University Teaching*, vol. 31, No. 2, 1982, pp. 74-81. In a survey of students who had left after completing all their work except their dissertation, the authors found that financial difficulties were an important but not dominant reason for leaving. Typically a combination of reasons prompted the decision.
17. Warren W. Willingham, "Predicting Success in Graduate Education," *Science*, vol. 183, Jan. 25, 1974, pp. 273-278. He reviewed several predictors: undergraduate grade point average (GPA), graduate record examinations (GRE) scores, college faculty recommendations, graduate GPA, performance on departmental examinations, and graduate faculty assessment. The only predictor of success in earning the Ph.D. was performance on the GRE advanced test.

Table 3-1. — Reasons for Leaving Graduate School: A Survey of 25 Ex-Graduate Students

Reasons for leaving doctoral program	Percentage	No. responses (N=70)
Financial (financial problems, good job offer, paid job interfered with thesis work)	39	27
Academic (problems with adviser, thesis research, peers)	36	25
Personal (personal or emotional problems, family demands, loss of interest)	27	19

NOTE: Very little study has been made of "failed" graduate students. This telephone survey was made of 25 advanced graduate students who never completed their dissertation. The students were Ph.D. candidates around 1970 and came from various universities. Their median age when interviewed was 39. Since each of the 25 respondents gave several reasons for leaving, the total number of responses was 70. Financial difficulties were especially cited by married students.

SOURCE: Penelope Jacks et al., "The ABCs of ABDs: A Study of Incomplete Doctorates," *Improving College and University Teaching*, vol. 31, 1982, pp. 74-81.

out” lots of students along the way. Attrition seems to be lower at the top research universities, although it is difficult to say whether that is because these universities get most of the best students, or because they have advantageous financial support and research programs.

Disadvantaged students — minorities, and to a lesser extent women and low-income students — are affected differently by finances in their decisions to attend graduate school. Blacks are significantly more likely to report current financial considerations (the need to improve finances and high debts) as major reasons for not going to graduate school. Minorities unfamiliar with the academic world, particularly Hispanics, may be unaware that graduate education is usually subsidized. Asians, many of whom go on to other professional education, worry less about the appropriateness of advanced education and the cost of graduate study.[18]

FINANCING GRADUATE EDUCATION

Since World War II the demonstrated national importance of R&D scientists and engineers has encouraged national investment in a small and select cadre of highly-educated, mobile graduate students. External support overcomes high costs and economic deterrents to advanced study. The Federal Government, universities, States, foundations, corporations, and other private groups have subsidized science and engineering graduate study not only through support of individual students, but through support for research institutions and important research problems.

Diverse and multiple sources of support are a strength of American graduate education. Each of these providers has different reasons for investing in graduate education, and different criteria and mechanisms for allocating funds. Together, they support a richer variety of students and research problems than any one source would support on its own. Diversity of support also enhances the financial stability of graduate programs.

Graduate education is expensive, including not only tuition, fees, and living expenses, but a student's share of research costs over 4 or more years. It is impossible to calculate exactly the cost of a single student’s graduate education, but an estimate of

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18. Consortium on Financing Higher Education, op. cit., footnote **11, p.** 22; Howard G. Adams, "Advanced Degrees for Minority Students in Engineering/’ *Engineering* Education, vol. 78, No. 8, May 1988, pp. 775-776.

$100,000 is not unreasonable. The tuition and fees charged to graduate students fall short of compensating for the actual burden incurred by the university. But universities and society receive many benefits from graduate students — e.g., immediate and future work as teaching and research assistants. Allocating costs of graduate education between research and instruction is a matter of judgment, not measurement.

Federal and other support at the graduate level has two major purposes: to cultivate a new generation of scientists and engineers to meet national R&D needs, and to buy research and teaching help at the universities. The central tools of this support — fellowships, traineeships, and research assistantships —are usually considered necessary reinvestment and maintenance for research and have very different characteristics from Federal undergraduate aid programs. Graduate support is usually awarded according to merit, and is linked to particular universities, departments, and/or fields and research topics. Most support requires research or teaching labor of graduate students in return for tuition subsidies and stipends.

Funding data show different patterns of support for graduate students in general, and for those who eventually earn Ph.D.s.[19] About one-half of graduate students intending to get a doctorate never earn a Ph.D. Some will earn Ph.D.s, returning research service for the investment of Federal and other external support during their apprenticeship. Because graduate students need support <u>during</u> their training, it is impossible to fund Ph.Ds.; we can only fund prospective Ph.D.s. Certainly some students

19. Information on support of graduate students and of Ph.D.s is collected in different ways and is not completely comparable. Some differences in patterns of support for graduate students and Ph.D.s would be expected, since one measures support for all graduate students (by full time, part time, and type of institution), while the other looks only at that subset of graduate students who make it through to a Ph.D. (About 75,000 new full-time graduate students, only some intending a Ph.D., entered doctorate-granting institutions annually in the late-1970s, and about 19,000 Ph.D.s graduated about 6 to 7 years later.) The most obvious explanation of differences in patterns of graduate student and Ph.D. support would be that successful graduate students (i.e., Ph.D.s) have a certain pattern of support, and unsuccessful ones another. Differences in methodology might account for some differences in the two databases. Graduate student support information is provided by the student's host department in response to National Science Foundation surveys: Ph.D. data are provided by the Ph.D. recipients themselves in the National Research Council's Survey of Earned Doctorates (conducted for the National Science Foundation). It would be helpful to have reliable financial aid information about graduate students through the course of their doctoral study, from Ph.D. recipients and those who drop out. The Department of Education is conducting an in-depth study of undergraduate and graduate student financing; the results on graduate education are forthcoming.

show outstanding promise; indeed, fellowships are designed to find and support these students. Others, however, do not blossom until later in their careers.

Sources of Graduate Student Support

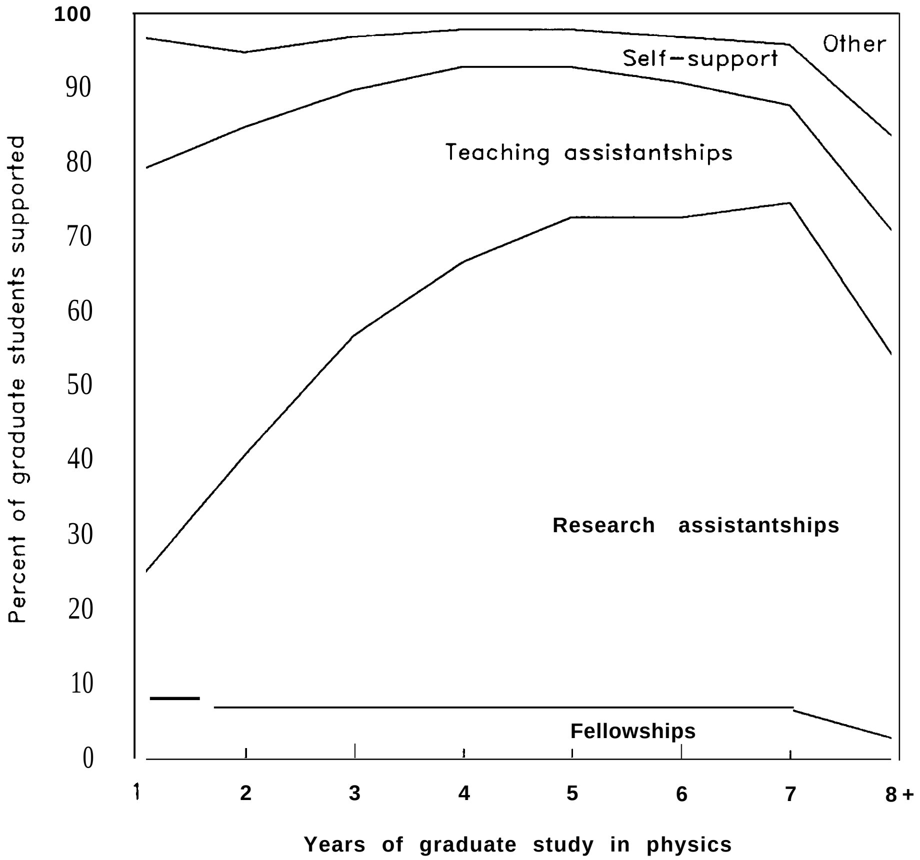
Graduate students obtain support from many sources. Most use several sources at one time, including personal funds and spouse's salary, since one form of aid rarely covers tuition, fees, living expenses, and research costs.[20] In addition, the major sources of support often change during the period of graduate study; as most awards are only made for one or a few years, there is an intrinsic instability to the life of a graduate student (see figure 3-2). Most students work during the first 1 or 2 years (or more) as teaching assistants, fulfilling the university's need for undergraduate teaching, while taking classes and developing a thesis topic. Then they may receive a research assistantship or fellowship, which allows them to work in the laboratory full time on thesis-related research. During the early, less focused years of graduate study, the student may not be prepared to benefit from that sort of freedom. Family support and loans are widely used as supplements to primary institutional or Federal support.

The university department is the gatekeeper for nearly all graduate student support funds, including external Federal or corporate funds (see figure 3-3). For example, Federal training grants are awarded to departments, which in turn select the students who will receive traineeships under that large grant. Research support usually goes to individual faculty, or to departments, who then hire graduate students as research assistants. Very few dollars go directly from the funding source to the student without passing through the guiding hands of departmental administrators and faculty, who must evaluate student potential and needs as part of the delivery of graduate education.

Direct Federal support is not the dominant source of funds for graduate students. Institutional support (mostly teaching assistantships (TAs) awarded by the university) and self-support are more common. In 1986, 71 percent of science and engineering graduate students received substantial external support; 41 percent received their primary support from institutions and States, 20 percent from the Federal Government. Other sources of stipends, including corporations and foundations, supported 7 percent of science and engineering students, and foreign sources supported 3 percent (mostly foreign students)

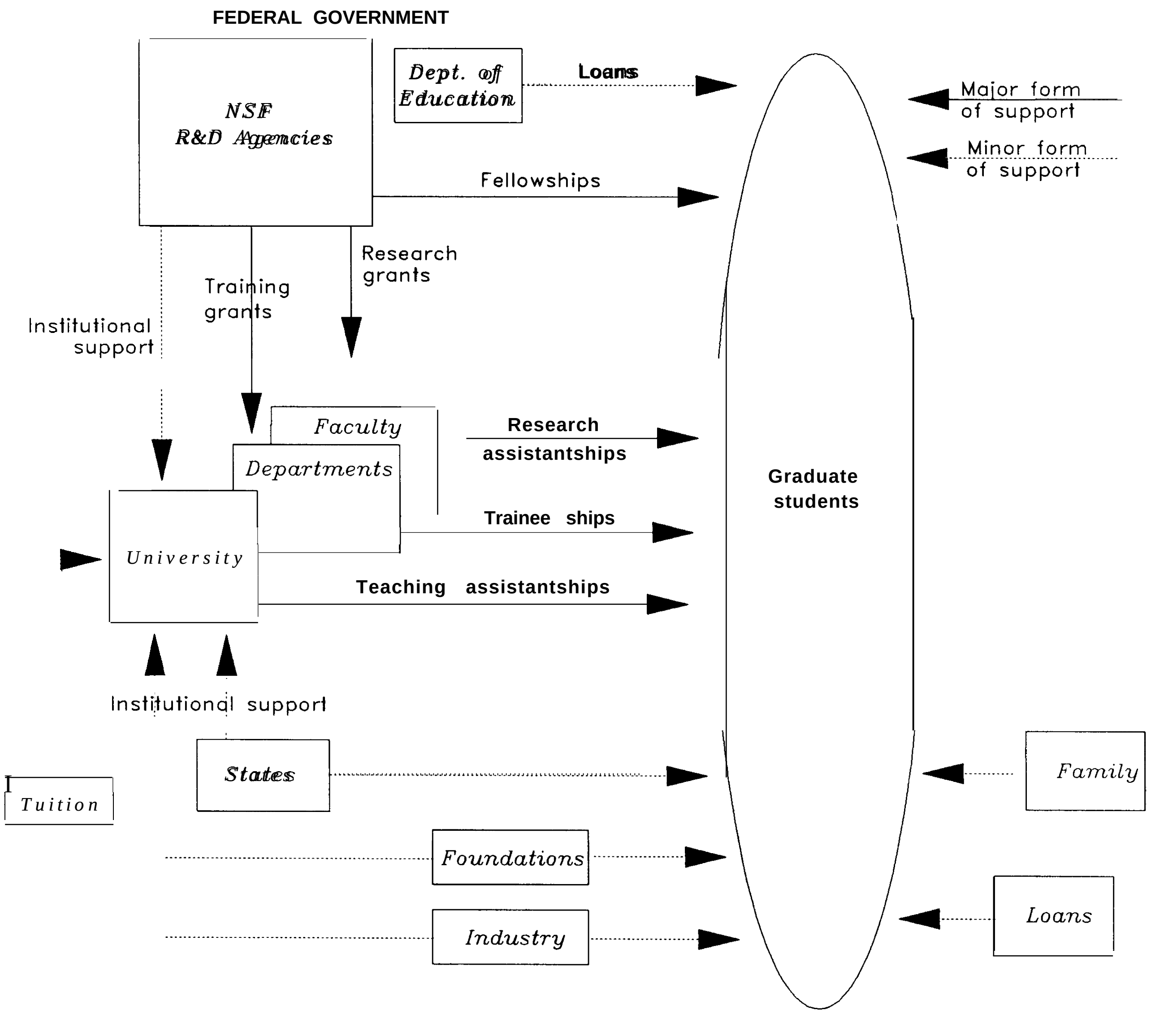
20. Moonlighting may be an important supplementary source of support. Nothing is known about how much science and engineering graduate students work outside of their graduate programs, but some surely do.

Figure 3–2.–Sources of Support for Graduate Physics Students, by Number of Years of Study, 1986-87 Students



SOURCE: American Institute of Physics, 1986-1987 Graduate Student Survey, Pub. No. R–207-20 (New York, NY: American Institute of Physics, 1988).

Figure 3-3.-Paths of Support for Graduate Education



SOURCE: Office of Technology Assessment, 1988.

(see table 3-2). Twenty-nine percent supported themselves.[21] In the past decade, institutional support, including local and State funding, has grown while Federal support has declined (see figure 3-4).[22] Corporate support has grown slightly; it is the primary source of support for only 1 percent of science and engineering Ph.D.s (see table 3-3).

The availability and type of funding affect successful completion of a Ph.D. There are significant variations, however, by field, gender, and race and ethnicity in the relationship between graduate student funding and completion of science and engineering Ph.D.s. These are explored below.

Federal Support for Graduate Study

About 50,000 science and engineering graduate students depend primarily on Federal support, mostly in the form of fellowships and research assistantships (RAs).[23] This number has fluctuated slightly since the late-1960s, declining to a low of 41,000 in 1973, then climbing slowly to 53,000 in 1980, and receding slightly thereafter (see figure 3-5). Enrollments have risen substantially since then, however, so that despite steady Federal support in numbers of students, the proportion of graduate students with Federal support has declined. This decline has occurred in all fields (see figure 3-6). In 1986, about 20 percent of full-time science and engineering graduate students received the bulk of their support from the Federal Government. (At the peak of Federal support, in 1966, 40 percent received Federal support.)

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21. National Science Foundation, *Academics cience/Engineering Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), p. 138. This is based on full-time graduate students in doctorate-granting institutions. (The distribution is about the same for full-time students in master's-granting institutions, with less Federal and more institutional, self, and other support.) Federal support is focused on the "core" Ph.D.-bound population, full-time students in doctorate-granting institutions. The data are for 'primary support," which masks the fact that most students receive support from several sources; many of those who are getting the bulk of their support from Federal sources also may be using family funds, loans, or university aid to make ends meet.
22. Ibid., p. 138. National Research Council, unpublished data from the Survey of Earned Doctorates. The data are reported by Ph.D.s themselves rather than the department, as is the case with National Science Foundation data on graduate student support. This accounting may lead to understating the extent of Federal support and overstating institutional support.
23. Ibid., p. 152. Full-time graduate students in doctorate-granting institutions. In 1986, 51,367 (20 percent) received their primary support from the Federal Government. Among full-time students in all institutions, 52,748 (19 percent) were federally supported. Federal support usually is confined to students working full-time fora Ph.D.

Table 3-2. — Graduate Students' Primary Support, by Source of Support and Field, 1986
(in percent)

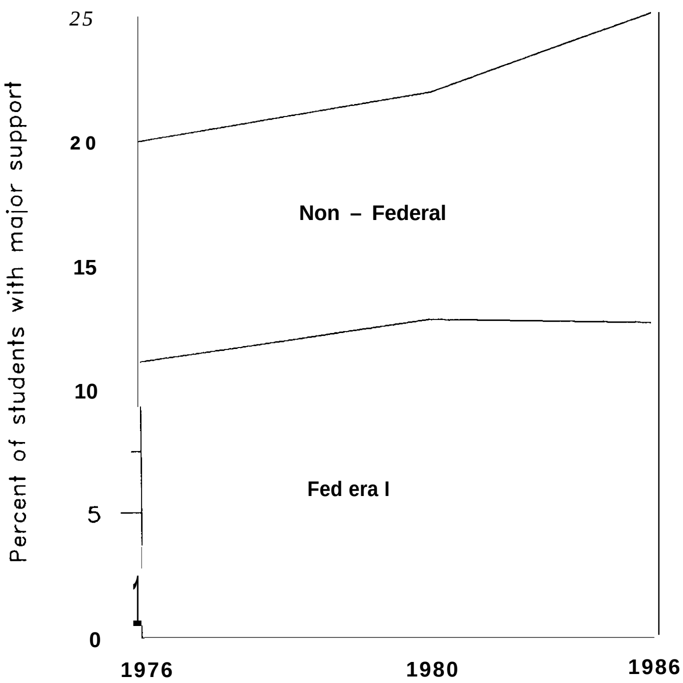
	Institutional[a]	Federal	Personal[b]	Other[c]
Natural Sci/Eng (n=190,384)	40	24	24	11
Science/Engineering (n=259,980)	41	20	29	10
Engineering	33	21	29	17
Computer science	32	13	44	11
Mathematics	70	8	17	5
Physical sciences	52	35	6	7
Earth sciences	38	28	23	11
Life sciences	39	28	24	9
social sciences	44	7	42	7
Psychology	45	9	40	6

[a] Includes State support.
[b] Includes loans.
[c] Includes corporate and foreign support.

NOTE: Full-time graduate students in doctorate-granting institutions.

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

Figure 3-4.–Percent of Graduate Students with Major Support by Research Assistantships, Federal and Non-Federal, 1976-86



NOTE: Data for 1978 are interpolated.

SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), pp. 128, 160- 161; and National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85–300 (Washington, DC: 1985), p. 129.

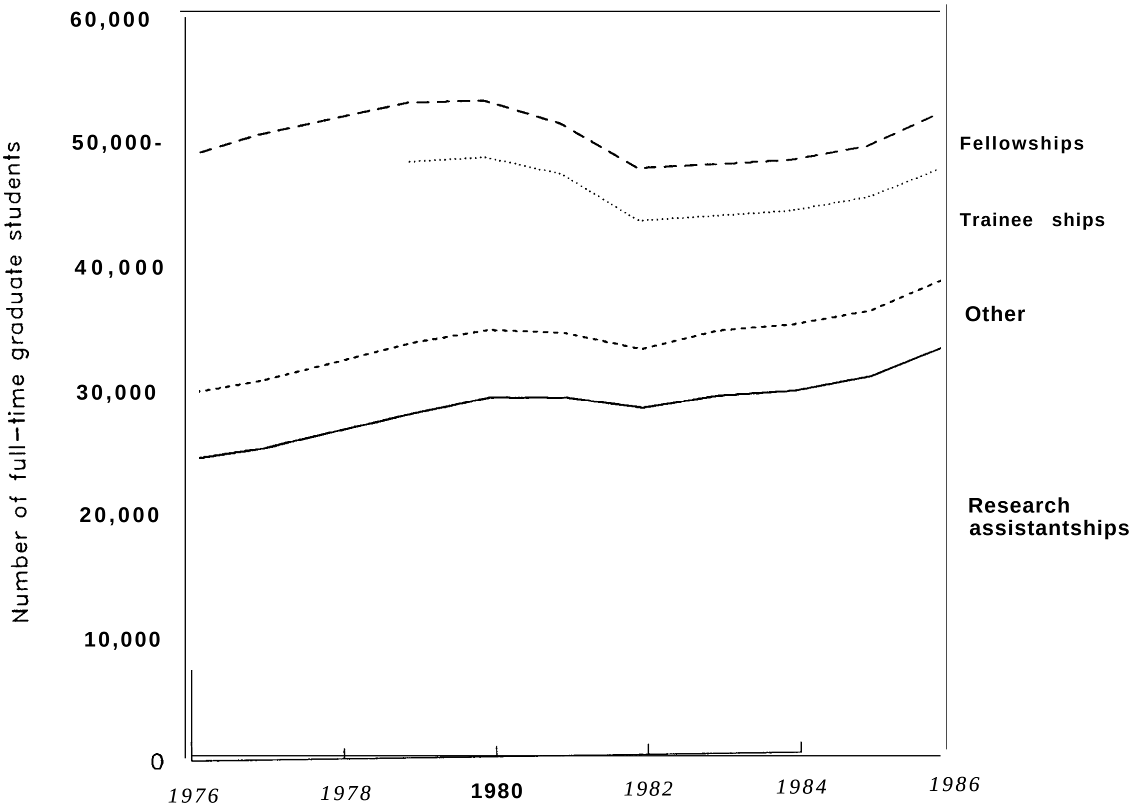
Table 3-3. — Primary Source of Support of Ph.D.s, by Field, 1986
(in percent)

	Institutional[a]	Federal	Personal[b]	Other[c]
All fields (26,232)[d]	45	7	42	6
Science/engineering (16,388)	32	10	28	16
Engineering (2,754)	68	6	16	10
Computer science (340)	58	4	26	12
Mathematics (600)	74	5	14	7
Physical sciences (3,076)	81	5	11	4
Life sciences (4,829)	50	19	24	7
Social sciences (4,789)	38	7	50	5

[a] Includes state support.
[b] Includes loans.
[c] Includes corporate and foreign support.
[d] Number of Ph.D.s reporting source of support (not total Ph.D.s); includes foreign citizens.

SOURCE: National Research Council, unpublished data.

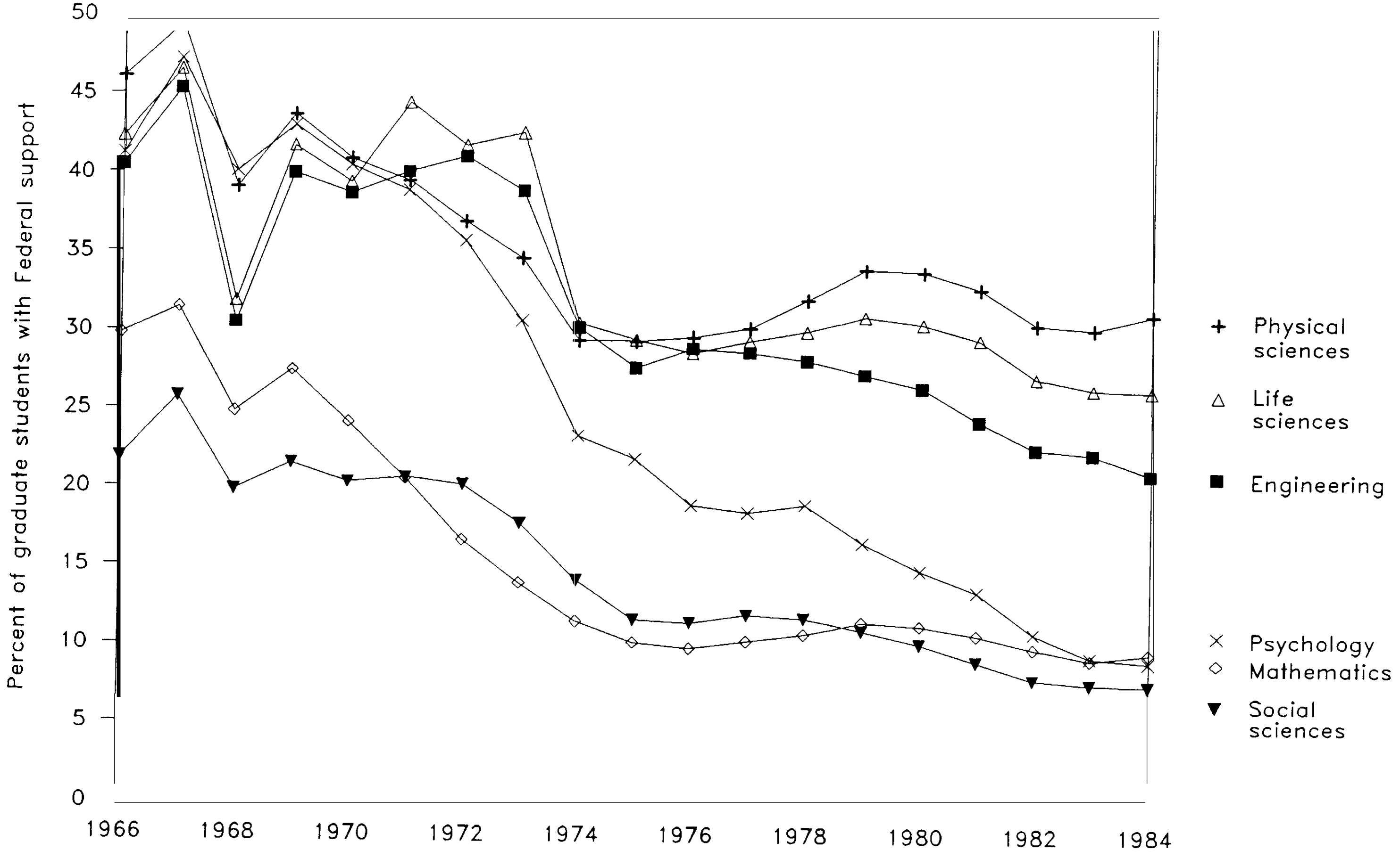
Figure 3-5.-Federal Support of Full-Time Graduate Students in Ph.D.–Granting Institutions by Type, 1976–86



NOTE: Data for 1978 are interpolated.

SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), p. 152; and National Science Foundation, Academic Science /Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 129.

Figure 3-6.—Percent of Graduate Students With Federal Support, by Field, 1966-84



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

Federal support varies by field (see figure 3-7). In the physical sciences, over one-third of graduate students are federally supported. A high proportion of life science students also benefit from Federal support, reflecting long-standing Federal interest in basic biomedical research. In mathematics and social sciences only about 10 percent of graduate students are supported by Federal funds, although for different reasons. Mathematics departments provide a great deal of service teaching, so most graduate students are supported by institutional teaching assistantships.

Mechanisms of Support for Graduate Study

Direct support for graduate students in science and engineering takes four primary forms:

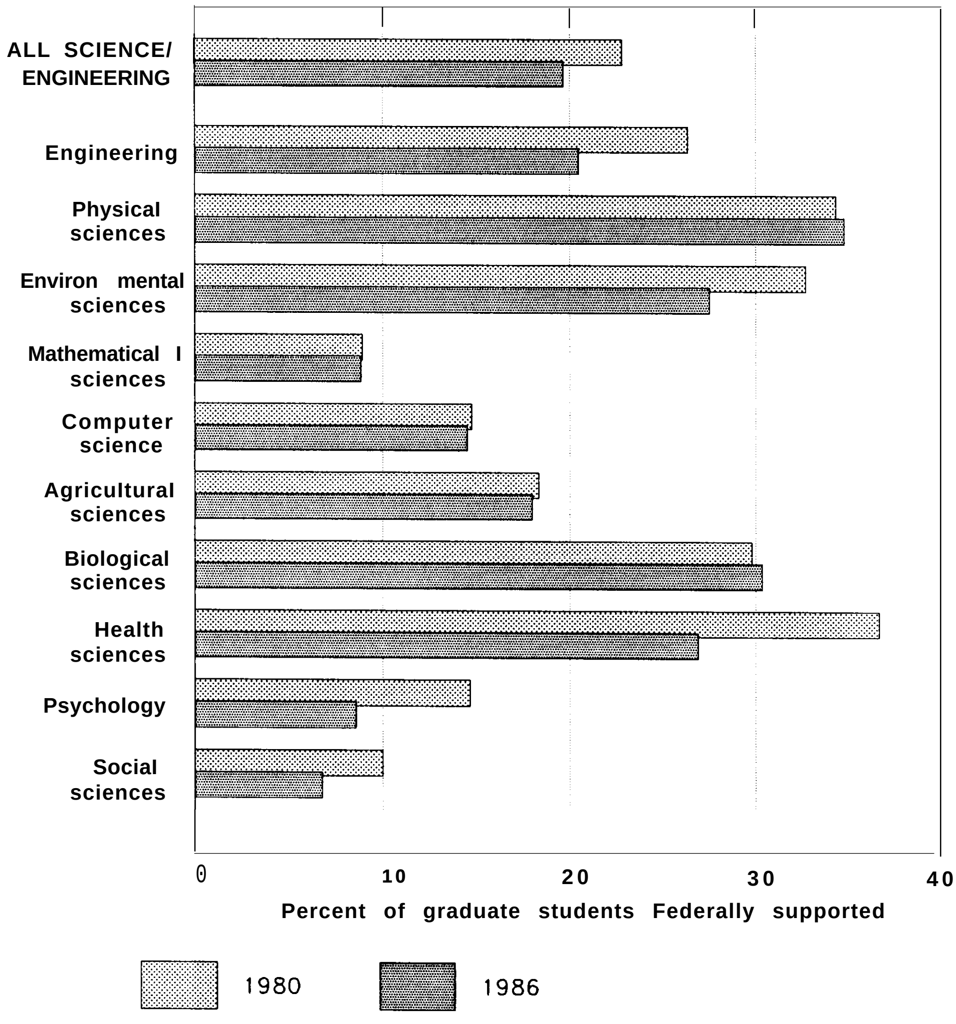
- fellowships awarded, on merit, to individual graduate students by the Federal Government, the university, or private sources;
- traineeships, awarded by departments who have received Federal or other training grants;
- RAs, tied to research grants and contracts awarded to principal investigators in university departments; and
- TAs, awarded by the university in exchange for teaching duties.

Indirect funding comes from private and government grants to support the research and education infrastructure and are awarded to universities, departments, and centers. Another form of indirect funding is State subsidies of public universities. Both types are used for faculty salaries, equipment, facilities, and overhead. Private and federally guaranteed loans provide a supplementary source of assistance to graduate students.

Research Assistantships. RAs linked to research grants are the most important form of support for science and engineering graduate students. RAs typify the apprenticeship model of graduate study: they put students into the laboratory with faculty mentors, placing them on the fast track toward thesis research, a Ph. D., and publications. Although often not considered part of science and engineering education budgets and policies, RAs are the primary support of one-quarter of graduate students and have been used by over one-half of science and engineering Ph.D.s.[24] RAs are

24. National Science Foundation, op. cit., footnote 21, p. 151 (full-time graduate students in Ph.D.-granting departments); and National Research Council, Summary *Report **1986:** Doctorate Recipients From **United States** Universities* (Washington, DC:

Figure 3-7.-Percent of Federally Supported Graduate Students by Field, 1980 and 1986



SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), pp. 128, 147.

dependent on their mentor to obtain and maintain research funding. Some argue that overreliance on RAs and the reduction of academic research support may channel graduate students' training to those faculty with strong research support; others see no problem, and in any case the current level does not seem to impose undue restrictions.

With the decline in fellowships and traineeships, RAs have become relatively more important. Non-Federal RAs have been growing much faster than Federal RAs. In 1986, for the first time in recent decades, more RAs were supported by non-Federal sources than by the Federal Government. About one-half of RAs are federally funded, although this proportion varies greatly by field. In fields with a strong Federal R&D presence and a research and graduate rather than a teaching and undergraduate orientation, such as physics, more RAs are federally funded. The rest of RAs come, through the department and faculty, from nonfederally funded research projects or institutional funds (see figure 3-8).

Nearly 30,000 science and engineering graduate students work as RAs on Federal funds. National Science Foundation (NSF) research grants support about 10,000 students each year, compared to about 1,500 per year on NSF fellowships.[25] Even at the National Institutes of Health (NIH) with its extensive training grant program, RAs are more widespread than fellowships and traineeships.

Since the decline in Federal fellowships and traineeships beginning in 1970, RAs have by default become a relatively more important source of Federal support. Some worry that overreliance on RAs may reduce opportunities for young graduate students to experiment with different courses and faculty, and may lead to premature specialization, although there is no solid evidence that this is happening.[26]

RAs are disproportionately concentrated in the top doctorate-awarding institutions, which is not surprising given the similar concentration of research funds: 50 universities have one-half of all full-time graduate students and 60 percent of all RA-supported graduate students.[27] As Federal R&D dollars hasten the development of new fields, graduate students and Ph.D.s will follow.[28] However, rising overhead rates at

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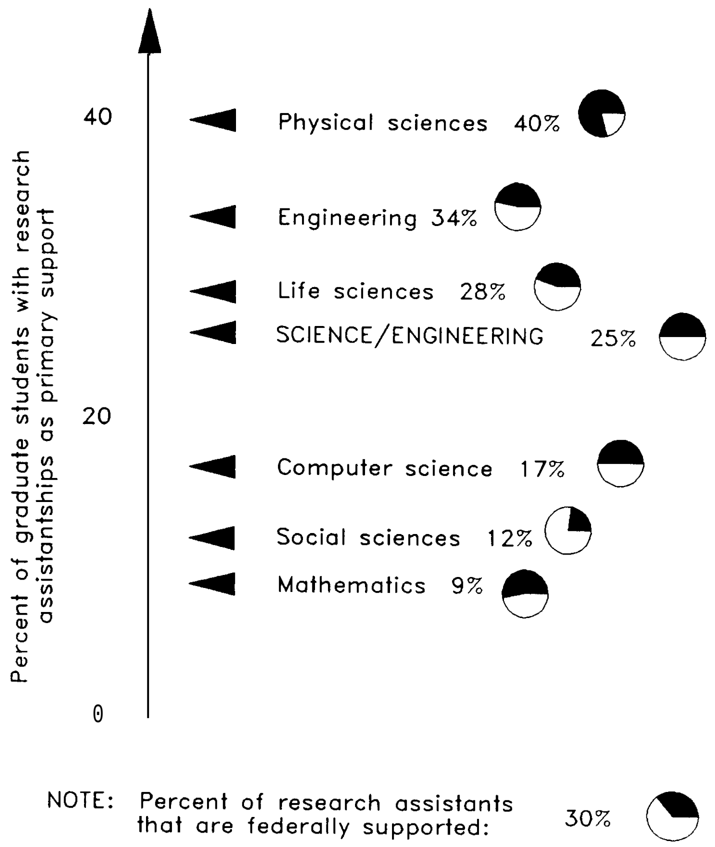
National Academy Press, 1987), p. 54.

25. National Science Foundation, Comptroller's Office, unpublished data, 1988.
26. Snyder, op. cit., footnote 8, p. 36.
27. National Science Foundation, op. cit., footnote 21.
28. Susan E. Cozzens (cd.), "Theme Section: Funding and Knowledge Growth," *Social Studies of Science,* vol. 16, No. 1, February 1986, pp. 3-150.

Figure 3-8.-Full-Time Graduate Students With Research Assistantships in Doctorate-Granting Institutions, by Field, 1986



SOURCE: National Science Foundation, Academic Science /Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88–307 (Washington, DC: 1988), pp. 128, 159–160.

universities may dilute the benefits to graduate education of increased Federal research support, even though universities protect graduate students as much as possible against the ill effects of constrained research budgets.[29]

Fellowships, Training Grants, and Teaching Assistantships. Fellowships and traineeships, with their generous stipends and few strings, are especially important to give students flexibility and time for independent work.

Fellowships are designed as elite mechanisms, to give a few of the "best" generous support and inspire the rest. Federal and private fellowships are awarded directly to the best students, regardless of the institutions they attend, though these students tend to migrate to the major research universities. Fellowship recipients earn their degrees faster and are more likely to join the science and engineering work force than those without such support. Federal fellowships in particular have been a quick and easy way to "buy" new Ph.D.s.[30]

Less than 10 percent of graduate students, however, enjoy fellowship support. The prestige of these awards makes them disproportionately important in providing quality education and in luring students into fellowship areas of study. Fellowships are portable, and require no formal service. Recipients of portable fellowships gravitate to the major research universities, so fellowships tend to enrich the richest institutions. Awards include a generous stipend ($10,000-$20,000) and an institutional allotment.

Most fellowships are awarded for 3 years; the money can usually be used over a longer period of up to 5 years. Some agencies have special dissertation support fellowships, usually awarded for 1 year. Many also have programs that encourage graduate students to spend a summer doing research at a government laboratory. Most agencies also have postdoctoral fellowships and/or research associateships.

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29. Graduate students benefit more from individual investigator grants than any other form of support. About 5 to 15 percent of the average research grant to an individual investigator goes to graduate research assistantships (RAs), though the proportion varies by field and by funding agency. National Science Foundation grants support more, and the Department of Defense fewer, RAs per research grant dollar. Information based on personal communications with agency program officers.

30. See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, *OTA-SET-377* (Washington, DC: U.S. Government Printing Office, June 1988), pp. 78-80.

The Federal Government supported about 4,500 graduate fellows in 1986, about 20 percent of all graduate fellows.[31] The number has been increasing in the past few years, although it is still below the annual level of 5,000 in the late-1970s, and the peak of nearly 12,000 in 1969. Federal fellowships constitute only a tiny amount of all Federal support, and reach less than 2 percent of graduate students. Many agencies have recently increased their fellowship stipends to attract more students, and to compensate for recent moves to tax fellowships.

Training grants are awarded, through national competition on the basis of merit, to institutions or departments for training in specific areas. They are usually multiyear packages covering faculty salaries, seminars, supplies, equipment, and predoctoral and postdoctoral student stipends. The institutions select the graduate students who receive traineeships. The Federal Government supports about 60 percent of them.[32]

The life sciences rely heavily on training grants, which NIH uses as its major mechanism of support. About 18 percent of life science Ph.D.s received NIH training grants.[33] Such grants, however, offer lower than average stipends. A payback provision in NIH's National Research Service Awards is designed to keep supported Ph.D.s in research.[34]

An NIH-sponsored study of training grants emphasize their multiple benefits for training as well as departmental and institutional development:[35]

- They support the research training environment for students, including research supplies and guest faculty seminars.

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31. National Science Foundation, op. cit., footnote 21, p. 152. The numbers refer to full-time graduate students in Ph.D.-granting institutions with Federal fellowships as their primary source of support. (Because of their size, fellowships are always the primary source of support.)
32. Ibid., pp. 156-157.
33. National Research Council, unpublished data from the 1987 Survey of Earned Doctorates. This has been fairly stable over the past 5 years.
34. National Science Foundation (NSF) training grants assisted institutional development and expansion in the 1960s, but no longer exist. From 1964 to 1973, NSF training grants supported over 8,000 students. U.S. Congress, General Accounting Office, *University Funding Mechanisms: Federal Funding Mechanisms in Support of University Research,* GAO/RCED-86-53 (Washington, DC: February 1986), p. 110.
35. Commission on Human Resources, National Research Council, Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel, *Personnel Needs and Training for Biomedical and Behavioral Research, 1981 Report* (Washington, DC: National Academy Press, 1981), pp. 7-10, 74-76.

- They permit a high degree of student choice in sampling courses and faculty, more so than RAs tied to individual research projects.
- They foster broad basic training rather than premature specialization.
- They create institutional continuity and a focus on graduate training.

According to this study, recipients of traineeships were more apt than nontrainees to co replete their degrees, enter research careers, and publish.[36] Although the grant recipients studied were a select group of NIH trainees and thus might be expected to perform above average with any support, it does show that the traineeship system—the nature of the training grant and the selection process used to identify recipient institutions and students — succeeds in training highly able researchers.[37]

Teaching assistantships are awarded by the university in direct exchange for a student's help in teaching one or more undergraduate courses. TAs are the primary source of support for a little over 20 percent of full-time graduate students. They are used quite widely; over one-half of science and engineering Ph.D.s report that they held a TA during their studies. Mathematics graduate students are particularly heavy users of TAs because of the heavy demand on mathematics departments to provide "service" instruction for undergraduate and graduate students in almost every field of study. Mathematics graduate students receive fewer RAs and fellowships. The Federal Government awards less than 1 percent of TAs, about 500 annually, most in the life and social sciences. The number of federally funded TAs has declined, while overall TAs have risen.[38]

Although widely used, especially during the early years of graduate school, TAs are less desired by students than RAs or fellowships. Students do not get as much 'career credit" for TAs even though they may gain useful experience and provide valuable service in the classroom and laboratory. Teaching takes time away from the graduate student's

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36. Porter Coggeshall and Prudence W. Brown, *The Career Achievements of NIH Predoctoral Trainees and Fellows* (Washington, DC: National Academy Press, 1984). A similar study was conducted on National Institutes of Health postdoctoral trainees: Howard H. Garrison and Prudence W. Brown, *The Career Achievements of NIH Postdoctoral Trainees and Fellows* (Washington, DC: National Academy Press, 1986).
37. The same study reported that cutbacks in institutional training grants result in reduced opportunities for seminars and travel to professional meetings, and a narrowing of students' choices of mentors to those who have research grant support, thus eliminating from consideration young faculty who have yet to receive such awards. Coggeshall and Brown, op. cit., footnote 36.
38. National Science Foundation, op. cit, footnote 21, p. 163.

research, and graduate students may not be able to teach a subject directly related to their work. At worst, they indenture students, prolong graduate study, and highlight the tension between research and teaching on campus. However, TAs provide valuable teacher training for the student. Too little is made of the value of apprentice teaching: well-supported TAs can draw attention to teaching as part of graduate training, encourage good service teaching at universities, and provide female or minority role models for undergraduates.

About 30 percent of graduate students are primarily self-supporting, mostly with their own earnings and family savings, supplemented by loans. This is up from about 20 percent in 1969. Borrowing is a subsidiary source of support for most graduate science students. Graduate students tend to borrow in the first 3 years of their study, then turn to research support, while students in the professions (i.e., medicine and law) borrow consistently through their periods of study. Most borrowing is done by full-time students.[39]

Loan use has risen substantially. Loans were used by about one-third of 1987 Ph.D. recipients, compared to 12 percent in 1972. There is no good data on the extent of borrowing and the amount of debt incurred during graduate school.[40] Overall, the number of graduate and professional postbaccalaureate students who borrowed under the Guaranteed Student Loan program tripled from 1977 to 1983, and their average total indebtedness rose from $4,882 to $10,244,[41]

Reliance on self-support varies greatly by field, from only a few percent in the physical sciences to over 40 percent in computer sciences and the social sciences (see figure 3-9). In particular, the extent of borrowing and amount of debt incurred vary by field, being lowest in the physical sciences and highest in the social sciences, and reflecting the greater availability of stipend support in the natural sciences.[42]

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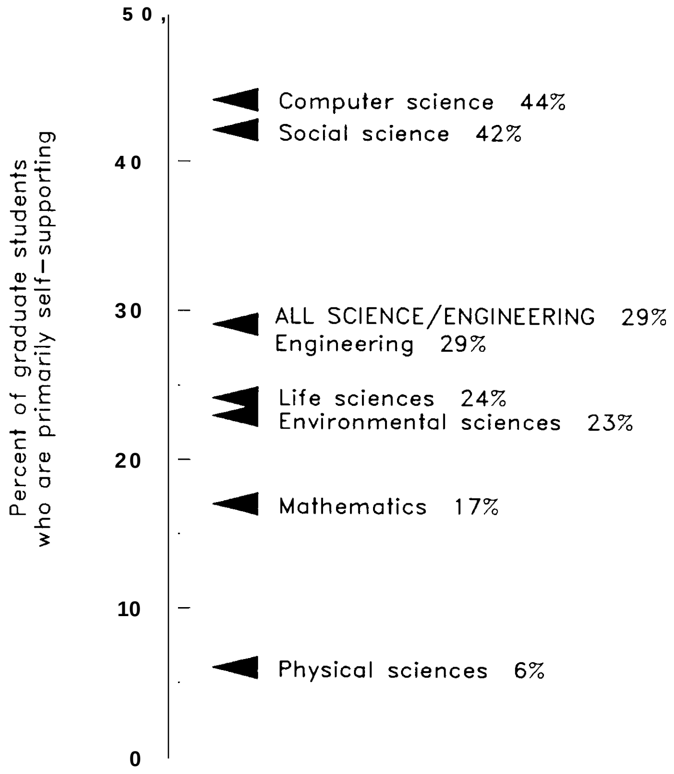
39. National Council on Student Financial Assistance, op. cit., footnote 7, p. 69. Students in historically Black colleges and universities (HBCUs) are much more likely to support themselves; among full-time students in HBCUs, 44 percent are self-supporting v. 31 percent of full-time students in all institutions (National Science Foundation, op. cit., footnote 21, pp. 42, 64).
40. Analysis of data from the Department of Education survey on graduate student financing are forthcoming. By comparison, a 1965 National Center for Education Statistics survey indicated that loans accounted for only 3.5 percent of full-time graduate student budgets (in all fields).
41. Pennsylvania Higher Education Assistance Agency, unpublished data, 1987.
42. Hauptman, op. cit., footnote 7, pp. 74-83; National Science Foundation, op. cit., footnote 21; and Herbert J. Flamer et al., Talented and Needy *Graduate and Professional*

Figure 3–9.–Self-Supportinq Full-Time Graduate Students in Doctorate-Granting Institutions, by Field, 1986



SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88–307 (Washington, DC: 1988), pp. 138-140.

The Leading Federal Role

The Federal Government plays a leading role in supporting graduate education and influencing the supply of science and engineering Ph.D.s. This is accomplished most directly through support for graduate students via fellowships, traineeships, RAs, and loans.

Federal R&D spending has a twofold pull on graduate education and is overall the most important influence on the size of the future science and engineering work force. It both creates a job market and provides direct support for graduate students in the form of RAs. Graduate enrollments and Ph.D. awards follow large changes in Federal R&D spending, although it is not clear how closely they track small changes.[43] Many other Federal research and higher education programs affect the demand for and quality of graduate education, and are therefore part of graduate education policy. And many other Federal tax, industry, and research policies, as well as immigration and civil rights legislation, have indirect influence by affecting the health and demographics of higher education and private investments in university research, graduate education, and Ph.D. employment.

Students: A National Survey of People Who Applied for Need-Based Financial Aid to Attend Graduate or Professional School in 1980-81 (Princeton, NJ: Educational Testing Service, April 1982). What do such field differences suggest: greater commitment by students whose salary prospects are lower though their incurred debt is higher, or merely lower expectations for remuneration? And is field-switching from baccalaureate to doctorate an indicator of flagged commitment? John W. Sommer, National Science Foundation, personal communication, November 1988.

43. Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," OTA contractor report, 1987. In the early 1960s, under the pro-science administrations of Kennedy and Johnson, the White House and the Bureauof the Budget applied arule ofthumb for R&D budgets that a 1 percent increase in graduate enrollments implied a 1 percent increase in academic research, plus an additional budget boost for 'increased sophistication of research." In those days (the reverse of the current situation), the push of expanding higher education enrollments, rather than the pull of national demand for R&D, dominated research training and academic support policy. Harvey A. Averch, A *Strategic Analysis of Science & Technology Policy* (Baltimore, MD: The Johns Hopkins Univesity Press, 1985), p. 80.

The makeup of the Federal portfolio of graduate student support has changed over the decades. In the past 15 years, Federal support of graduate education has shifted from direct fellowship and traineeship support to indirect support to RAs through academic research grants.

Federal aid, like all financial aid, encourages graduate school application, acceptance, and attendance.[44] Past increases in Federal support boosted graduate school enrollment and Ph.D. production. Pulled into the university by the Vietnam War push, college graduates of the mid-1960s were more likely to go on to graduate study in general, and doctorate programs in particular. This pattern holds for the best students as well.[45]

Graduate study has expanded greatly since World War II, in response to the pull of industry and academia for Ph.D. researchers and faculty, and the pressure of more college graduates seeking further education. As Federal R&D increased, so did the number of graduate students supported on Federal research assistantships, fellowships, and traineeships.

The Boom: 1959-1971

Graduate enrollments and doctorate production in science and engineering rose rapidly during the 1960s, as they did in all fields. Graduate enrollments in all fields more than doubled between 1958 and 1968, and Ph.D. awards tripled; one-fifth of

44. C. Ethington and J. Smart, ‘Persistence to Graduate Education,M *Research in Higher Education,* vol. 24, 1986, pp. 287-303; and Vetterand Hertzfeld, op. cit., footnote 43.
45. Frank Goldberg and Roy A. Koenigsknecht, The *Highest Achievers: Post-Baccalaureate Enrollment of Four Classes Between 1956 and 1981* (Evanston, IL: Northwestern University, Consortium on Financing Higher Education, January 1985), p. 17. The survey encompassed several hundred "high-achieving" students (the top3 to 5 percent) and a control group from eight selective institutions. In this study of the boom and bust in Federal support for graduate education, doctoral enrollments rose significantly from 1956 to 1966, then droppedby 1976. Among the high achievers, all the increase in 1966 was in doctoral enrollments; master’s enrollments actually declined, suggesting that students were more likely to go on not only to postbaccalaureate study, but also to doctoral programs. Doctoral enrollments rose the fastest, and fell the fastest. The control group, on the other hand, slightly increased its postbaccalaureate enrollment, but the increase was all in master’s programs.

baccalaureates went on to graduate school in 1955, compared to one-third in the peak years of 1967-68.

Graduate enrollments increased faster than simple demographic changes alone would account for. Healthy academic and industrial demand accounts for some of this increase, but the greater availability of stipends certainly enhanced the attractiveness of graduate school. Rapidly increasing Federal support pulled doctorate production along with it.[46]

This growth in education and research was launched with Sputnik, fueled by the Apollo program, and driven later by social goals such as equitable access. During this "golden era" of academic research and graduate education, Federal R&D spending doubled (in constant dollars). The National Defense Education Act of 1958 training grants program supported several thousand Ph.D.s who went on to productive careers in research and technical management (see box 3-B). Until the Apollo program was scaled down in 1967, Federal support of academic R&D increased by about 20 percent a year (in constant dollars), and the number of graduate students (in all fields) on Federal fellowships and traineeships rose from under 10,000 to over 50,000.

While Federal support for graduate study fueled this expansion, it was made possible by the swelling postwar pool of college-educated people. Ph. D. awards declined after Federal fellowships were cut back in 1969, despite continued high undergraduate enrollments. This suggests that the Ph.D. job market booms created by Federal and other research and education funding drove science and engineering graduate study more than did the sheer number of available students. Demand for Ph.D.s rose much faster than the rest of the labor market. Ph.D. production is indeed tied not to demographic trends but to the labor market for researchers.[47] Both the decline in R&D demand and the decline in Federal graduate support contributed to the slowdown in graduate study and Ph.D. production, although it is difficult to quantify the relative effect of the two.

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46. Snyder, op. cit., footnote 8, p. 20.
47. U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force*, OTA-SET-TM-35 (Washington, DC: U.S. Government Printing Office, December 1985), p. 41.

After the Boom

The boom, of course, had to end. Social and political priorities shifted away from Cold War-inspired science. In addition, many of the goals of the buildup — increased graduate enrollment and Ph.D.s, university development, faculty expansion, and increased R&D— had been achieved. From 1968 to 1974, the number of Federal Government fellowships and traineeships (in all fields) plummeted 85 percent [48] The number of Federal RAs dropped slightly, owing to a decline in Federal R&D support (in constant dollars). In the first years of the 1970s, first-year graduate enrollments plateaued after a decade of substantial annual increases.

By 1974 the proportion of graduate students relying on Federal support had dropped to 25 percent from the 1969 peak of nearly 40 percent. Infrastructure support was severely curtailed and science development programs were eliminated. Federal support retrenched to a more modest, though still substantial, level.[49]

The cutbacks differed among fields:

- Engineering and physical science were the most affected. Fellowships and traineeships dropped 90 percent, from 13,600 in 1969 to 1,500 in 1975, and National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and Atomic Energy Commission (AEC) research funds dropped 45 percent in real terms. Graduate enrollments and then Ph.D. production declined steadily for 6 years.
- The life sciences were less affected. Fellowships and traineeships declined by nearly 45 percent, but NIH and NSF research funds increased in real terms, mitigating the effects of the fellowship decline. Graduate enrollments and Ph.D.s held steady.
- Least affected were the social sciences. Although fellowship and traineeship support declined by two-thirds, graduate enrollments and Ph.D.s continued to increase slowly .[50]

48. Richard B. Freeman and David W. Breneman, ‘tForecasting the Ph.D. Labor Market: Pitfalls for Policy,” A Technical Report presented to the National Board on Graduate Education, Washington, DC, April 1974, pp. 12-13.
49. Snyder, op. cit., footnote 8, p. 16.
50. Ibid., pp. 31-32.

As Federal research spending picked up again in the 1970s, demand for research assistants went up and science and engineering graduate enrollments followed suit, but by varying degrees. Nearly all the early increases were in fields affected by funding for the War on Cancer. In the late-1970s, graduate science and engineering enrollments grew moderately and steadily. In the lively computer, semiconductor, and energy markets of the late-1970s and early-1980s, engineering became the fastest growing field. Enrollments in general grew in response to the job market, even though the numbers of graduate students with Federal support declined.

Increasing women's participation helped maintain graduate enrollments in the life and social sciences during this time. Universities resisted cutting faculty, departments, programs, or students in the face of budget cuts. Continued high undergraduate enrollments maintained demand for graduate students as teaching assistants.

Effects of Federal Support

Since to a great extent the ultimate source offending is "invisible" to the graduate student, whether their time and research supplies are paid for by the Federal Government or a corporation, the effects of a Federal fellowship or assistantship are to some extent similar to a fellowship or assistantship from any source. (And it must be remembered that most Federal support is distributed by the university.) However, Federal support often provides unique value insofar as it

- targets different or unique research problems that other funding does not support;
- provides more (or less) freedom in the recipient's activities and in choosing a research problem, although this freedom may be curbed by work on the research program of the student's mentor;
- targets a category of students or faculty (such as NSF's minority fellowships and program for women recentering the research work force);
- targets an underserved region or type of institution (such as the historically Black colleges and universities);
- is attended by particular national or scientific prestige (such as the few and prized NSF fellowships); and
- includes access to Federal researchers, equipment, or facilities, such as the national laboratories or NASA facilities.

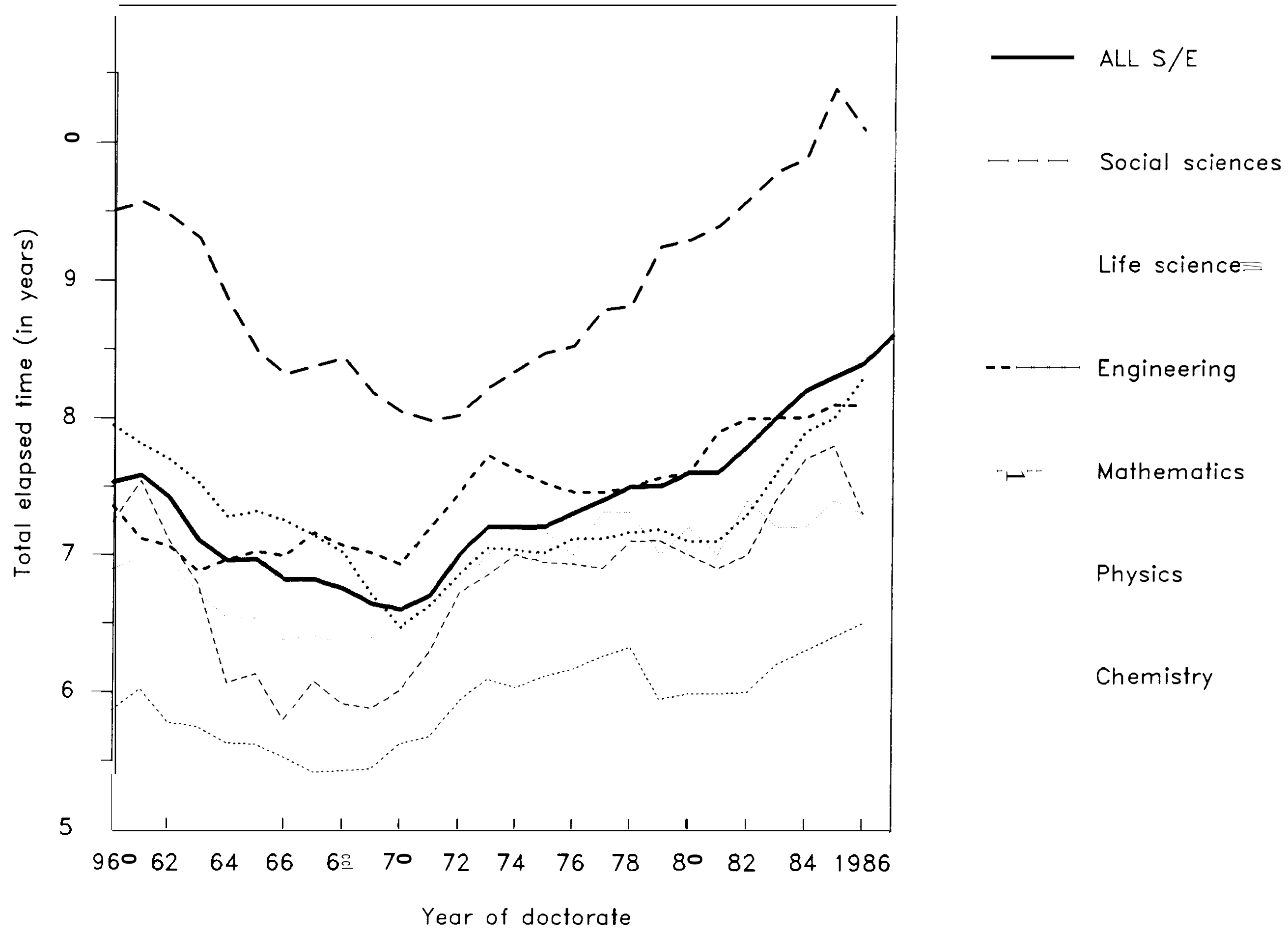
Federal support has several positive effects on science and engineering graduate students. First, it increases the number of science and engineering Ph.D.s.[51] Graduate science and engineering enrollment and Ph.D.s follow the pattern of Federal support for R&D and students. Graduate enrollments, then Ph.D.s conferred, rose during the 1960s, then turned down abruptly around 1970. During the 1970s, a comparable pattern emerged: the proportion of graduate students with Federal support declined beginning in 1971, and the number of Ph.D. awards declined beginning in 1974.

Second, Federal support encourages full-time study and shortens the time from B.S. to Ph.D.[52] During the boom in Federal fellowship/traineeship/RA support in the late-1960s, the average time from B.S. to Ph.D. declined, and the proportion of graduate students attending full time rose substantially. Since 1970 the time to Ph.D. has been steadily rising, from 6.6 years in 1970, to an all-time high of 8.6 years in 1987,[53] and the proportion of part-time graduate students rose (see figure 3-10). Although it is hard to say which is cause and which effect, as Federal support declined, graduate students were more likely to attend part time and on average took longer to get their Ph.D.s. Fellowships and traineeships, with minimal service requirements, provide students the financial freedom to concentrate on studies full time and the intellectual freedom to immerse themselves in the study and research that earns a Ph.D. Social science students, with the longest time to Ph.D., have the highest dependence on TAs and self-support, and the fewest RAs.

The close links between direct support and Ph.D. awards suggest that Federal support is vitally important to completion of a Ph.D. It is possible that a large portion of the increase in graduate enrollment, in some sense excessive in light of the much smaller increase in Ph.D. awards, is driven by the increase in baccalaureates awarded. The increase in graduate enrollments that began in 1974 follow an increase in science and

51. Vetter and Hertzfeld, op. cit., footnote 43, p. 34.
52. Ibid; and Richard Freeman, *The Market for College Trained* Manpower (Cambridge, MA: Harvard University Press, 1971), developed a model which related a 1 percent increase in the availability of fellowships to a 7.5 percent decrease in B.S. to Ph.D. time lapse. Also see Snyder, op. cit., footnote 8,p. 21.
53. National Research Council, Survey of Earned Doctorates, unpublished 1987 data. Registered time, 6.4 years for 1987 science and engineering Ph.D.s, has also been increasing.

Figure 3-10.-Elapsed Time Between B.S. and Ph.D., by Field, 1960-87



SOURCE: National Science Foundation, Science and Engineering Doctorates: 1960-86, NSF 88-309 (Washington, DC: 1988), pp. 128-9; and National Science Foundation, Science and Engineering Doctorates: 1960-82, NSF 83-328 (Washington, DC: 1983), p. 80.

engineering bachelor's graduates up to that time. The greatest increase in bachelor's graduates was among women and minorities; this same shift showed up in increased graduate enrollments.

Third, Federal support appears especially effective in helping women complete graduate study. Financial support is especially important for women, although a supportive environment may be more instrumental to success. Females completing Ph.D.s are more likely to have received Federal support, and female graduate students less likely, than their male counterparts (see box 3-C).[54]

Several studies further indicate that fellowships attract graduate students that might otherwise go to professional school, and that a decline in fellowships diverts students from Ph.D. study to professional school.[55] The Consortium on Financing Higher Education survey of eight selective institutions supports this conclusion: from 1956 to 1976, high-achieving students (in all fields) enrolled in postbaccalaureate education in steady proportions (85 percent), but there was a large shift from graduate school to professional school between survey dates 1966 to 1976 (as graduate school enrollment dropped from 54 percent to 35 percent, professional school enrollment rose from 33 percent to 53 percent).[56]

The mission research agencies play a major role in supporting graduate students; four out of five federally funded graduate students are supported by the mission agencies rather than NSF (see table 3-4). Mission agency prominence is due to RAs from agency university research grants. The NIH traineeship program is by far the single largest Federal graduate support program. Department of Education fellowships, though smaller in amount than most mission agency fellowships and not restricted to science and engineering, are used by many women and minority graduate students in science and engineering, particularly in the social sciences.

The largest Federal traineeship or fellowship program is NIH's National Research Service Awards training grants; the approximately $100 million spent on about 5,000 to 6,000 graduate trainees within that program is about 3 percent of NIH's research budget. Among the most prestigious Federal awards are NSF fellowships, which support

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54. Vetter and Hertzfeld, op. cit., footnote 43, p. 33.
55. Julia A. Heath and Howard P. Tuckman, "The Effects of Tuition Level and Financial Aid on the Demand for Undergraduate and Advanced Terminal Degrees," *Economics of Education Review,* vol. 6, No. 3, 1987, pp. 227-238.
56. Consortium on Financing Higher Education, op. cit., footnote 11.

Table 3-4. — Federal Fellowships and Traineeships, by Agency and Field, 1986

Agency	$	Full-time students, 1986
NIH/HHS	$204,339	8,335
NSF	25,152	1,545
Defense	518	378
NASA	7,920	a
EPA	2,809	a
Energy	550	a
Agriculture	4,679	a
Other	229	3,074
Total Federal	$246,196	13,332

Field	$	Full-time students, 1986
Life sciences	$192,038	8,923
Psychology	13,795	622
Engineering	10,797	1,005
Social Sciences	10,501	1,630
Mathematics	4,069	146
Chemistry	3,500	326
Environmental sciences	2,438	263
Physics	3,707	253
Computer sciences	500	164
Other	4,851	
Total Science/engineering	$246,196	13,332

[a] Agency total is included in "Other."

Key: NIH/HHS = National Institutes of Health/Health and Human Services
NSF = National Science Foundation
NASA = National Aeronautics and Space Administration
EPA = Environmental Protection Agency

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp. 154, 157; and National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year 1986,* NSF 87-318 (Washington, DC 1987), pp. 17, 23.

1,400 graduate students. Among other agencies, DoD, NASA, and the Department of Energy (DOE) are notable for their smaller fellowship and research support programs which bring students into agency and national laboratories. Several agencies, notably NIH and NSF, have special fellowships for minority students.

A consortium of universities, large companies, and government agencies (including DOE, the National Institute of Standards and Technology, and NASA) has started a new program, the National Physical Sciences Consortium for Graduate Degrees for Women and Minorities, to encourage women and minorities to complete Ph.D.s in science or engineering. Program sponsors each contribute something: universities cover tuition and fees, and companies and agencies provide student stipends and research opportunities.

Effects on Women

Women received about 27 percent of science and engineering Ph.D.s in 1987, but this varies greatly by field, from less than 10 percent in engineering to nearly one-half in the social sciences (see table 3-5).[57] The pattern of women's financial support is shaped by their choice of fields. Within any given field, the distribution of graduate student support varies little by sex (see table 3-6). But since women tend to concentrate in fields such as the social and life sciences, where RAs are less common than in other fields, women are substantially less likely to receive RAs.[58]

Women who earn Ph.D.s are actually more likely than men to have received NSF fellowships, NIH traineeships, and other Federal support in graduate school (see table 3-7). But full-time female graduate students are less likely to have Federal support (table 3-8). This may indicate that Federal support is particularly important for women to complete graduate study, although comparing data from two different surveys is risky. Women's propensity to attend part time further constrains their access to support.

Improving the participation of women in science and engineering demands effort on all fronts (see box 3-D). Programs dedicated to female science and engineering students include NSF's Research Opportunities for Women, which supports women scientists and engineers who have not yet been principal investigators or who are reentering the

57. National Research Council, Survey of Doctorate Recipients, unpublished 1987 data; U.S. Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," Staff Paper, January 1987.

58. National Research Council, *Summary Report 1984: Doctorate Recipients From United States Universities* (Washington, DC: National Academy Press, 1986), p. 40.

Table 3-5. — Science/Engineering Ph-D.s by Sex, Citizenship, and Field, 1987

	Women as percent of all Ph.D.s	U.S. women as percent of U.S. Ph.D.s[a]
Science/engineering	27	32
Engineering	7	10
Computer science	14	22
Life sciences	35	40
Social sciences	43	51

[a]"U.S." includes both U.S. citizens and foreign citizens on permanent visas (6 **percent),** and unknown citizenship (about 7 percent) of total.

SOURCE: National Research Council, Survey of Doctorate Recipients, unpublished 1987 data.

Table 3-6. — Selected Forms of Support for Ph.D.s, By Sex, 1986
(in percent)

	NIH traineeship/ NSF Fellowship		Research assistantship		Teaching assistantship		Own earnings		University fellowships	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
All Science/engineering	10	16	61	48	53	52	46	55	21	24
Natural science/ engineering	10	22	67	57	51	49	39	43	20	23
Physical sciences	6	7	72	71	70	72	34	32	22	22
Life sciences	21	29	56	50	39	40	45	48	20	23
Social sciences	8	10	38	37	58	54	67	69	26	24
Engineering	4	9	74	71	42	47	38	38	17	29

NOTE: Type of support not exclusive. Includes foreign citizens, most of whom are male.

Key: NIH = National Institutes of Health
NSF = National Science Foundation

SOURCE: National Research Council, *Summary* Report 1986, *Doctorate* Recipients *From United States Universities* (Washington, DC: National Academy Press, 1988), p. 54.

Table 3-7. — Science/Engineering Ph.D.s' Major Source of Support During Graduate Study, by Field and Sex, 1986 (in percent)

	Federal		Institutional		Other		Self[a]	
	Men	Women	Men	Women	Men	Women	Men	Women
engineering	8	6	61	69	7	8	23	17
Physical sciences	6	8	77	73	3	4	14	15
Life sciences	21	24	55	45	2	2	22	29
Social sciences	8	9	35	35	2	2	55	54

'Includes loans, which are primary support for less than 1 percent of Ph.D.s., except in the social sciences, where loans are primary support for about 7 percent of Ph.D.s.

NOTE: Financing data are self-reported This may lead to understating Federal and overstating institutional support, because some students may not know of the original source of department-distributed money. Percentages may not sum to 100 because of rounding.

;OU RCE: National Research Council, ***Summary** Report* 1986, *Doctorate Recipients From* ***Jnited States** Universities* (Washington, DC: National Academy Press, 1988), p. 25, and republished data.

Table 3-8. — Science and Engineering Graduate Students' Primary Source of Support, by Field and Sex, 1986
(in percent)

	S/E TOTAL		Engineering		Physical		Math/CS		Life		Social	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
All Federal	21	18	21	18	34	29	12	7	26	29	7	8
DoD, NSF, NIH	14	13	13	11	24	21	10	6	19	23	3	4
Other Federal	7	5	8	7	10	8	2	1	7	6	4	4
Institutional	41	41	33	35	47	51	48	53	42	36	45	43
Other U.S.	8	6	14	13	7	6	6	5	7	5	5	4
Foreign	4	1	4	2	2	1	3	2	5	2	4	1
Self	26	33	29	31	11	12	31	34	19	28	39	44

NOTE: Full-time in doctorate-granting institutions. Includes foreign citizens. Physical sciences includes physics, chemistry, and environmental sciences.

Key: S/E = Science/engineering
Math/CS = Mathematics/computer science
DoD = Department of Defense
NSF = National Science Foundation
NIH = National Institutes of Health

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp.141-146.

research community. Many professional societies have established special committees on women.

Effects on Minorities

The participation of Blacks and Hispanics in doctoral science and engineering degree-taking has increased very slowly in the past 10 years, despite several programs dedicated to minority students. (See table 3-9 for the proportion of Ph.D.s earned in science and engineering fields by U.S. minorities in 1987.)

Although the same proportion of minority as white Ph.D. recipients received their primary student support from stipends, Blacks are more likely than whites to use loans, and less likely to hold RAs.[59] Some Federal programs include:

- The Graduate Professional Opportunities Program of the Department of Education (now known as Javits Fellowships) which supports about 800 minority students in natural sciences, engineering, and law.
- NSF Minority Graduate Fellowships.
- NIH/National Institute of General Medical Sciences (NIGMS) Minority Biomedical Research Support Program (initially called the Minority Biomedical Support program), started in 1972 and closely affiliated with the NIH Minority Access to Research Careers (MARC) program.
- NIH/NIGMS MARC predoctoral training program. (MARC also includes programs for honors undergraduate research training, faculty fellowships, and visiting scientists.)
- Special programs for Indian education administered by the Bureau of Indian Affairs and the Department of Education's Indian Education Programs, although these do not focus on science and engineering per se.

Foreign Graduate Students

Foreign students are increasingly visible and important in American graduate programs in science and engineering. The United States benefits from this flow of

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59. Michael Nettles, *Financial Aid and Minority Participation in Graduate Education*, A Research Report of the Minority Graduate Education Project (Princeton, NJ: Educational Testing Service, 1987), p. 5.

Table 3-9. — U.S. Science/Engineering Ph. D=, by Race/Ethnicity and Field, 1987

	U.S. Minorities as percent of U.S. PhD.s		
	Blacks	Hispanics	Asians
All Science/engineering	2.1 (n=335)	2.3 (n=359)	6.0 (n=946)
Engineering	1.3	1.8	17.1
Physical sciences	1.0	2.3	6.8
Physics	0.9[a]	1.6[b]	4.6
Chemistry	0.9[b]	3.0	7.4
Environmental	0.4[a]	1.1[a]	4.0
Mathematics	2.8	2.8	10.4
Computer science	0.7[a]	1.5[a]	9.5
Life sciences	2.4	2.0	5.6
Biological	1.9	2.0	5.4
Agricultural	2.3	2.4	6.3
Health	4.9	1.7[b]	5.5
Social sciences	3.7	3.5	3.1
Psychology	3.3	3.5	1.7
Economics	2.9[b]	2.7[b]	8.7
U.S. minorities as percent of all science/engineering Ph.D.s, including foreign citizens	1.7	1.8	4.7

[a] n<15
[b] n<10
[c] Non-U.S. citizens on temporary visas. Included as U.S. citizens are non-U. S. citizens on permanent visas (6% of U.S. science/engineering Ph. D.s) and those of unknown citizenship (7% of U.S. science/engineering Ph. D.s). Non-U.S. citizens on permanent visas almost always stay in the United States.

SOURCE: National Research Council, Survey of Earned Doctorates, unpublished 1987 data.

talent; many of these students stay, acquire permanent visas, and add to the scientific vitality of the Nation. Less than one-half of foreign science and engineering Ph.D. recipients remain in this country for at least a few years; the percentage is slightly higher, about 60 percent, for engineering and computer science. About 80 percent of the increase in foreign-origin scientists and engineers in the U.S. work force between 1972 and 1982 was due to students who stayed on after earning the doctorate.[60]

The overall share of science and engineering Ph.D.s awarded to foreign students is increasing, 22 percent in 1987.[61] Foreign graduate students concentrate in high-growth, high-payoff fields, and in technical areas rather than humanities and social sciences: one-half are in engineering and 25 percent in the sciences. They account for 3 percent of U.S. higher education enrollment overall, 5 percent of B.S. degrees in science and engineering, and 25 percent of full-time science and engineering graduate students in Ph.D. institutions.

Foreign students go on to fill many faculty positions. Nearly one-half of young engineering faculty are foreign. Among those under age 36, the proportion of foreign nationals rose from 11 percent in 1975 to 47 percent in 1985 (see figure 3-11).[62]

Foreign students generally are ineligible for direct Federal support (fellowships and traineeships) and thus tend to rely on university TAs and RAs and support from home.[63] There also are limitations on having them as research assistants on defense-sponsored research grants. While foreign students are required by the Immigration and Naturalization Service to demonstrate that they will be funded for at least 1 year of study, once enrolled in graduate schools they can seek the same institutional fellowships and assistantships as Americans. Not surprisingly, foreign Ph.D. recipients are more likely than Americans initially to have support from their families or home countries, and to receive institutional support such as TAs and RAs.[64]

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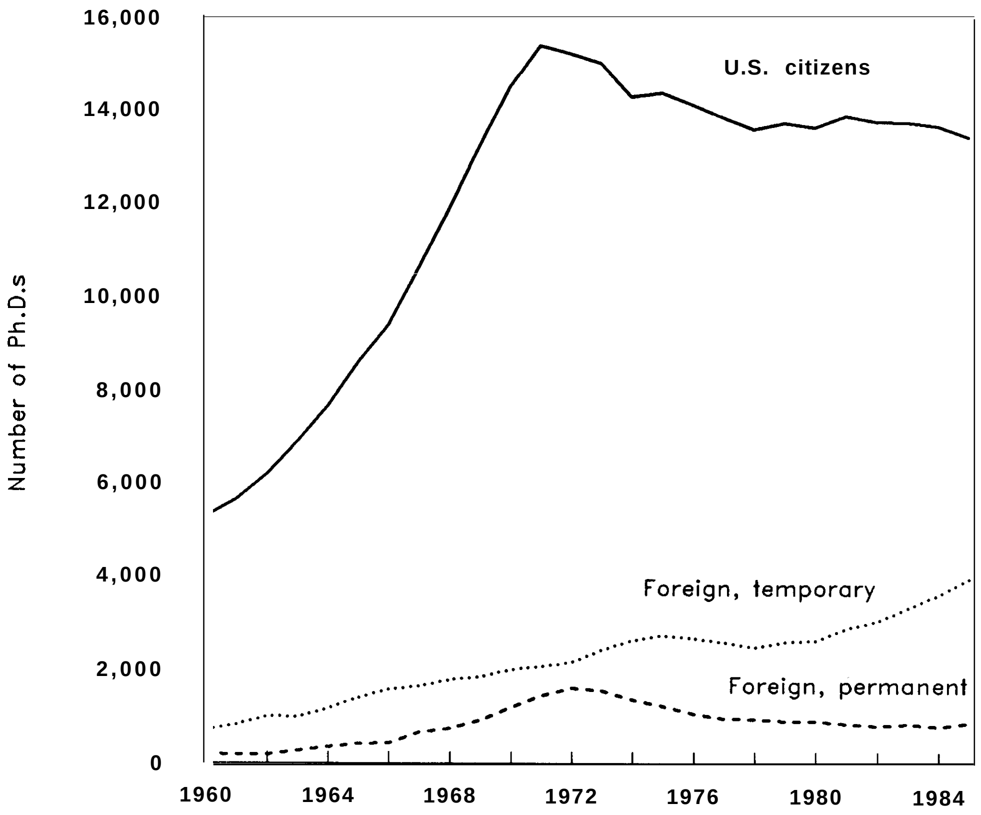
60. Michael G. Finn, Oak Ridge Associated Universities, 'Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982," June 1985.
61. The growth of foreign students in engineering is discussed further inch. 4.
62. National Research Council data, cited in *Manpower Comments,* July-August 1987, p.27.
63. Annual fellowship stipends range between $10,000 and $18,000 (paid directly to the student) and, in addition, usually cover tuition and fees (paid to the university, usually about $6,000). One wonders whether the growth of foreign students in U.S. graduate schools has expanded the use of research assistantships (for which all students are eligible), or vice versa. Christopher Hill, Congressional Research Service, personal communication, November 1988.
64. National Science Foundation, *Foreign Citizens in U.S. Science and Engineering:*

Figure 3-11 .- Science/Engineering Ph.D. Awards by Visa Status, 1960-85



NOTE: U.S. citizens include unknown citizenship.

SOURCE: National Science Foundation, Foreign Citizens in U. S. Science and Engineering: istory, Status, and Outlook, NSF 86-305 revised (Washington, DC: 1986), p. 91.

Luring student talent has overtaken mid-career immigration as the way the United States acquires qualified foreign scientists and engineers. Admissions of scientists and engineers as permanent immigrants have been between 7,000 and 13,000 a year (less than 2 percent of all immigrants), with fluctuations in part reflecting Federal immigration quotas tied to U.S. labor market conditions. By comparison, foreign nonimmigrant enrollment in higher education is 344,000, in science and engineering about 166,000, and in science and engineering graduate study about 75,000. In addition, another few thousand scientists and engineers enter on temporary and exchange visitor visas. Many graduating foreign students enter the work force, usually exchanging their student visas for other temporary visas.[65] In 1985, 21,000 students (about 8 percent of that year's entry) and 8,000 temporary workers (11 percent) were adjusted to permanent residence.[66]

Visa, naturalization, and employment policies affect the entry of foreign scientists and engineers into the work force. To attract and rebuild a base of U.S. citizens in science and engineering, most Federal student support programs require U.S. citizenship (usually a permanent visa insufficient). There have always been restrictions, for national security reasons, on DoD and DOE support. Restrictions are most likely in fields of obvious and pressing importance to national military or economic security and in fields in which the concentrations of foreign students are highest. These two areas tend to be one and the same. Another bone of contention is that perhaps 10 times as many foreign students are trained in the United States as U.S. students are trained in other countries. But foreign students are not uneconomic drain on institutions or the U.S. economy.[67]

Immigration policies have affected the numbers and the national origins of students in science and engineering. Immigration quotas do not apply to entry on temporary visas, including student visas. Such temporary entry is generally unrestricted. Entry through the student route, switching from temporary student visa to temporary worker status and then immigration, is the dominant route of entry for scientists and engineers.[68] The

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History, Status, and Outlook, Special Report NSF 86-305 revised (Washington, DC: 1987), pp.29, 105.

65. Immigration and Naturalization Service, *Statistical Abstract 1987* (Washington, DC: 1987) p. 12.

66. Immigration and Naturalization Service estimates.

67. Elinor G. Barber (cd.), *Foreign Student Flows*, Report on a Conference, Apr. 13-15, 1984, IIE Research Report No. 7 (New York, NY: Institute for International Education, 1985), p. 12.

68. Office of Technology Assessment, *op. cit.*, footnote 30, pp. 63-65.

student route has become more important since changes in immigration policy made it more difficult for workers to obtain a visa unless they were already employed by a U.S. firm.

Economic and political conditions in the countries of origin dominate foreign student flows. A sevenfold increase in students from the 13 0PEC countries in the 1970s was responsible for one-half of the total increase; in the late-1970s and early-1980s, non-OPEC countries increased emigration on student visas. Ten countries contribute nearly one-half of the foreign students studying in the United States. Because of this concentration, foreign enrollments are sensitive to changes in host country policies.

Continued high inflow of foreign students could help keep academic demand for faculty high through the demographic trough, until the expected upswing in faculty demand in the mid-1990s. They may also ease fluctuating enrollments in particular fields, such as petroleum engineering, although generally they and U.S. students gravitate to the same fields.

Institutional Support of the Infrastructure for Graduate Education

A high-quality infrastructure — equipment, facilities, and libraries— is vital to high-quality graduate training. Institutional support is one pillar of the foundation of the Nation's capability for graduate education and scientific research (see box 3-E). Since the late-1970s there has been increasing concern within the academic community over the deterioration of equipment and facilities. A 1987 Congressional Research Service report summarized the academic consensus: ". . . current conditions of research facilities may have serious implications for the quality of future scientists and engineers produced by the Nation's universities."[69]

Most concern over deteriorating infrastructure centers on research capability; it is important also to ensure that policies attend to training capability. Some argue that obsolescent facilities and equipment lead to teaching of outmoded methodologies.[70]

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69. U.S. Congress, Congressional Research Service, *Bricks and Mortar: A Summary and Analysis of Proposals to Meet Research Facilities Needs on College Campuses,* a report prepared for the Subcommittee on Science, Research and Technology, House Committee on Science, Space, and Technology, (Washington, DC: U.S. Government Printing Office, September 1987), p. 23.
70. Ibid., pp. 157-158; and U.S. Congress, Office of Technology Assessment, "Scientific Equipment for Undergraduates: Is It Adequate?" Staff Paper, September 1986.

Universities that lack state-of-the-art equipment and facilities report difficulty attracting and keeping the best graduate students and faculty.[71]

Spending on equipment and facilities is about 15 percent of academic science and engineering expenditures, with facilities taking the major share. This rate is lower than it was in the mid-1960s (when it peaked at about 20 percent), but has been increasing slowly from a low of about 9 percent in 1970, in response to widely voiced concerns. Most infrastructure funds come from non-Federal sources (see figure 3-12). Donations from individuals, foundations, and industry have been fostered by Federal tax policy. The Federal Government supports about 65 percent of equipment expenditures; the Federal share for facilities is now below 10 percent and is declining.[72] However, Federal support has been more stable than other sources. Private universities have been particularly dependent on Federal funds and private contributions; public universities benefit from State support. All universities also rely heavily on issuing tax-exempt bonds.

Federal institutional development programs were stimulated by rapid post-Sputnik and baby-boom growth in graduate education and research. Concern over capacity drove expansion of university infrastructure. At the peak of Federal programs in 1965, direct Federal contributions supported about one-third of university spending on all types of science and engineering facilities, and one-half of spending on research facilities. Federal programs declined 85 percent (in real terms) between 1965 and 1984.

Special institutional support should be distinguished from another major vehicle of Federal support for university infrastructure, namely indirect costs or overhead— the light bulbs, heating and air conditioning, libraries, copy machines, sewer hookups, and, of course, support staff, which are necessary to all departments. Support for overhead is built into most research and training grants, and is now 25 to 30 percent of R&D support. Infrastructure — building operation and maintenance, building depreciation, and libraries— is about 42 percent of overhead.[73] In 1986, the Federal Government spent

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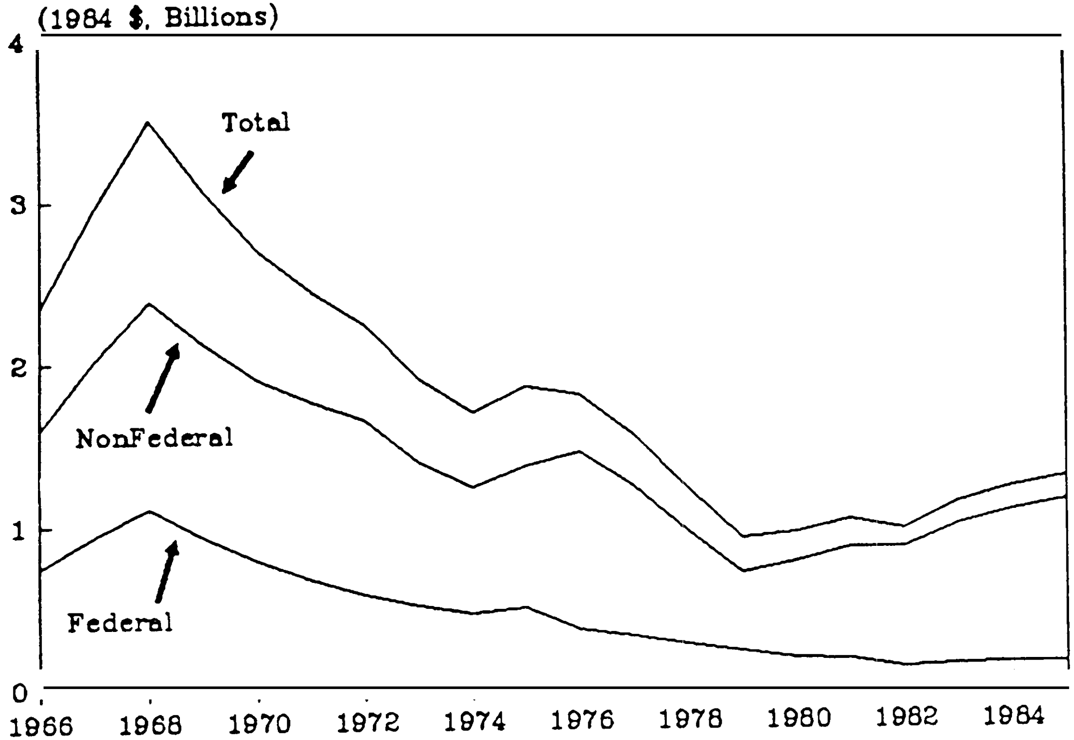
71. Association of American Universities, *The Nation's Deteriorating University* Research Facilities (Washington, DC: July 1981), p. 11.

72. National Science Foundation, "Academic Expenditures for Science and Engineering: Past, Present, Future," PRA Working Draft, April 1988, p. 6.

73. National Science Foundation, *Future Costs of Academic Science/Engineering* (Washington, DC: April 1988). Based on a survey of top research universities, these estimates should be reasonably representative. Administrative costs are the largest and fastest rising component, over one-half of overhead. Student services are about 1 percent.

Figure 3-12.–Academic Science/Engineering Facilities Expenditures, by Source of Funds



SOURCE: National Science Foundation, Academic Expenditures for Science and Engineering: Past, Present, Future, Working Draft (Washington, DC: April 1988), p. 37.

about $350 to $400 million for equipment. In addition, smaller equipment and supplies are funded through regular research grants.

There is disagreement over how best to provide infrastructure support and the extent of the burden the Federal Government should shoulder.[74] Should the role of the Federal Government be simply to award research and training money, on a negotiated overhead rate, and let universities apportion that money among immediate operating needs of students, supplies, and faculty, and longer-term capital needs for chromatography, computers, and laboratories? Or should the Federal Government take a more substantial role by directly funding equipment, facilities, and other institutional underpinnings?

As growth slowed, special institutional development was curtailed, leaving a base of Federal institutional support, primarily through overhead on research and training grants. This baseline has usually favored the best. In times of slow or no growth in education and research, R&D and training programs have usually concentrated in a small number of well-funded, well-equipped departments, with awards based on quality, efficiency, and the importance of a "critical mass" of people and research projects (see table 3-10). Equipment and facilities are concentrated in the top research universities (table 3-11).

However, facilities and large equipment cannot be funded by either small individual investigator awards or by indirect cost recovery. The large capital outlays needed for construction, major renovation, and large equipment demand big chunks of money. NSF estimates that $1 to $3 billion in equipment and $1.5 billion for facilities are urgently needed to compensate for underfunding in the past.[75]

Equipment and facility needs varies greatly by field and research problem. Manufacturing engineering, for instance, may rely on automated equipment costing

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74. See Congressional Research Service, op. cit., footnote 69. The history of Federal programs for facilities funding is discussed in ch. 4 of the Congressional Research Service report; impacts on education are summarized on pp. 151-160; policy options are discussed in chs. 5 and 7. The report reviews and integrates studies by the Association of American Universities, the National Science Foundation, the General Accounting Office, and others. See also, Stephen J. Fitzsimmons et al., *The Capacity of American Colleges and* Universities to *Train Science and Engineering Talent: A SurVey of Universities, Scientists, Foundations, and* the Private Sector, a report to the National Science Foundation Division of Policy Research and Analysis (Cambridge, MA: Abt Associates, Inc., Jan. 15, 1985), pp. 24-26, 65-69.
75. National Science Foundation, op. cit., footnote 72, pp. ii-iii.

Table 3-10. — University R&D Support and Ph.D. Production, 1986

	Univ. (ranked by Fed. R&D $)	Number (& rank) 1986 NSE Ph.D.s		Fed. acad. S/E support, 1986	Federal f/t support, 1986	
1.	Johns Hopkins	141	(41)	$457,525	10,075	(2)
2.	MIT	436	(2)	207,867	7,260	(7)
3.	Stanford	392	(4)	195,454	9,866	(3)
4.	U. of Washington	246	(13)	157,154	7,745	(5)
5.	UCSD	140	(44)	140,878	5,147	(15)
6.	Columbia	211	(20)	142,430	5,575	(13)
7.	UCLA	281	(12)	133,150	5,255	(14)
8.	U. Wise-Madison	406	(3)	138,827	4,793	(17)
9.	Cornell	360	(7)	149,599	4,425	(18)
10.	Yale	150	(36)	123,849	9,143	(4)
11.	U. Michigan	340	(8)	120,168	5,950	(12)
12.	Harvard	234	(14)	125,127	11,919	(1)
13.	UCSF	46	(112)	113,828	7,525	(6)
14.	U. Pennsylvania	181	(26)	112,305	6,926	(lo)
15.	U. Minnesota	371	(6)	114,473	3,746	(21)
16.	UC-Berkeley	557	(1)	104,958	6,996	(9)
17.	U. Ill-Urbana	379	(5)	103,091	1,509	(40)
18.	Penn State	230	(16)	99,665	1,009	(51)
19.	USC	176	(28)	80,145	1,518	(38)
20.	U. Texas-Austin	296	(10)	76,288	935	(52)

NOTE: There is about a 70 percent overlap; 14 of the top 20 Federal R&D recipients are in the top 20 natural science and engineering (NSE) Ph.D. producers. The other 6 institutions are listed below.

Other High NSE Ph.D.-Producers

Purdue	316	(9)	57,424	871	(57)
Ohio State	294	(11)	78,746	715	(65)
Michigan State	233	(15)	59,788	653	(69)
UC-Davis	230	(17)	45,798	1,520	(37)
Texas A & M	226	(18)	53,341	394	(98)
U. Maryland	212	(19)	59,098	523	(84)

SOURCE: National Science Foundation, *Federal Support ot Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year: 1986,* NSF 87-318 (Washington, DC: 1987), pp. 19-24; and National Science Foundation, *Science and Engineering Doctorates: 1960-86,* NSF 88-309 (Washington, DC: 1988), pp. 153-156.

Table 3-11. — Distribution of Graduate Student Primary Support and Federal R&D Among Top 100 Research Universities, 1986
(in percent)

	Full-time grad students	All research assistantships	All fellows	All trainees	All teaching assistantships	self/ other[a]	Federal academic
Top 10[b]	12	15	15	17	8	9	26
Top 20	25	30	32	34	20	22	40
Top 50	46	52	56	56	40	37	75
Top 100	67						86

[a]Overall, self-support is about 77 percent of self/other support.
[b]Universities ranked in order of receipt of Federal academic R&D funds (out of 325 total doctorate-granting institutions)*

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp. 329-342; and *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year: 1986*, NSF 87-318 (Washington, DC: 1987), pp. 21-22.

hundreds of thousands of dollars. Mathematics research may demand multi million dollar supercomputers or simply chalk and blackboard. The Federal Government cannot underwrite these costs, but it can recognize their magnitude and act as a kind of investment counselor.

Postdoctoral Appointments

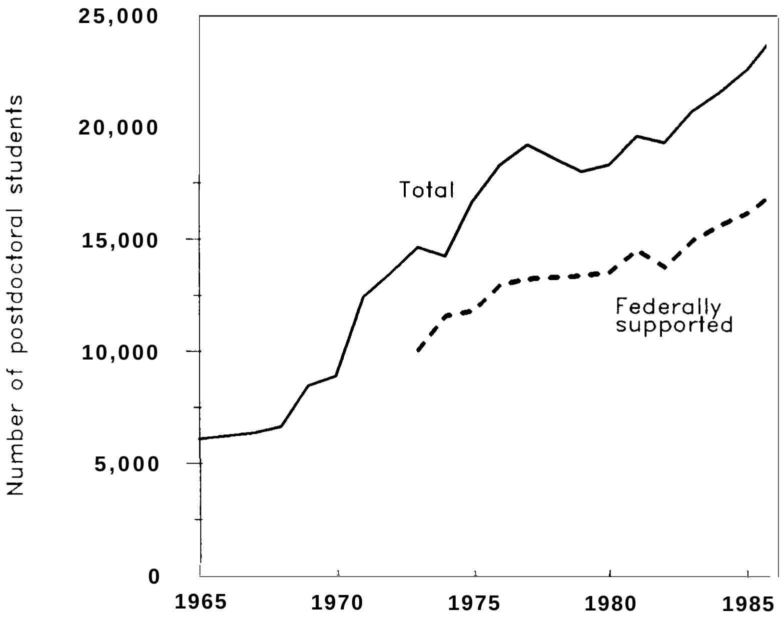
The postdoctoral appointment, as noted earlier, is a holding tank for talented Ph.D.s who cannot land the "right" job. Thus, it is seen by many as both a means of augmenting one's skills and as a proving ground, particularly in the life sciences. Postgraduates establish credentials as independent researchers, carving out their own research programs as distinct from those of their mentors and demonstrating the productivity that will earn them permanent faculty positions. Postdoctoral students are much more likely than graduate students to be supported by the Federal Government. Two-thirds are in the life sciences; 70 percent of life sciences Ph.D.s take postdoctoral appointments, compared with about one-half of Ph.D.s in the physical sciences.

Urgent national needs can be met most quickly by shifting postdoctoral support.[76] The number of postdoctoral appointments have increased steadily, from 6,100 to over 24,000 between 1965 and 1986. Approximately three-quarters of these appointments are supported by Federal funds, a proportion that has remained stable since data were first collected in the early-1970s (see figure 3-13). Unlike support of graduate students, Federal postdoctoral support has remained stable, increasing in the number of awards as the number of candidates increase.

With the current scarcity of science faculty positions in universities, more recent Ph.D.s are entering nontraditional academic jobs as nonfaculty research staff (see box 3-F). There are about 5,000 nonfaculty research staff, compared to over 20,000 postdoctoral students, in universities, according to NSF. Compared to postdoctoral researchers, nonfaculty research staff are less likely to be in life sciences, and more likely to be in engineering and social sciences.

76. William Zumeta, "Anatomy of the Boom in Postdoctoral Appointments During 'he 1970s: Troubling Implications for Quality Science?" Science, Technology, & *Human Values, vol. 9, No. 2,* spring 1984, pp. 23-37. For example, the mobilization of biomedical specialists to accelerate basic research on AIDS should soon be apparent sheerly in the size of the postdoctoral pool of intra- and extramural scientists supported by the National Institutes of Health.

Figure 3-13.–Science and Engineering Postdoctoral Students in Degree-Granting Institutions, Total and Federally Supported, 1965-86



NOTE: 1978 data are interpolated.

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

Field Differences: The Pluralism of Ph.D.s

While this chapter has focused on broad field differences, disaggregated analysis is necessary to assess the quantity and quality of new Ph.D.s. However, the smaller and more specialized the scientific field being studied, the less predictable are changes in the factors that affect graduate enrollments and doctoral degrees awarded. Small changes in the total supply of scientists and engineers can mask significant adjustments within and among fields.[77]

For example, research physicists and astronomers depend mainly on Federal research funds awarded to universities and national laboratories. In chemistry, university research is overshadowed by industrial R&D, which employs large numbers of R&D chemists at all degree levels, particularly Ph.D.s. Environmental sciences (earth, atmospheric, and ocean sciences) is a small field, with a core of geologists dependent on the health of the oil and mining industries and a collection of interdisciplinary researchers responding to environmental R&D priorities.

Within fields, shortages and surpluses occur in specific research specialties. Thus, there are now surpluses of new graduates in particle physics and petroleum geology, and at the same time shortages in optical physics, condensed matter physics, and geochemistry. In some instances, there are continuing mismatches between supply and demand, as in the continuing overproduction of particle physicists and theoretical physicists relative to research opportunities. Many earth scientists are employed in the petroleum and mining industries, which are buffeted by business cycles and resource policies. Mathematics is a key field of research that depends largely on academic employment, not only for research but for service teaching.

The life sciences are big and diverse, including the biological sciences, the health and medical sciences, and the agricultural sciences. Sophisticated new instrumentation and the accelerating pace of discovery have blurred the boundaries between these fields. The Federal Government has long had a substantial stake in research and training in these fields, because of the high national priority vested in health-related basic and clinical research. Agriculture has been the longest standing federally supported research and training area, but funding is much lower than in the health and biological sciences.

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77. Office of Technology Assessment, op. cit., footnote 57. For an example of subfield specialization in physics, see Roman Czujko et al., Society Membership *Profile: The Pattern of Subfield Associations* (New York, NY: American Institute of Physics, Manpower Statistics Division, 1986), pp. 9-16.

Much of the growth and relative stability in the employment of agricultural scientists is in the extensive nationwide network of U.S. Department of Agriculture research facilities and the State agricultural experiment stations associated with the land-grant universities.

Social sciences are different from natural science and engineering. Psychology is the largest field in the social and behavioral sciences, accounting for one-half of Ph.D.s. Over one-half of recent Ph.D.s in psychology have been awarded in clinical subfields, and new Ph.D.s increasingly enter private or public clinical practice instead of pursuing traditional academic careers.[78]

Engineering Doctorate Education

Engineering doctorate education differs from science doctorate education in several ways. Generally, graduate education in engineering is dominated by master's students oriented to the industrial labor market (see chapter 4). For those who complete doctorates, attractive industry jobs and salaries also lure new Ph.D.s away from faculty jobs. Unemployment among Ph.D. engineers is nil.

Because of this and the great interest of foreign students in studying engineering, less than one-half of engineering graduate students are American. The problem is accentuated by the strong demand of defense-related employers for American engineers. The end result is that there has been a continuing, and at sometimes critical, shortage of young American Ph.D.s interested in faculty positions (the primary source of new faculty).

What can be done? Some universities have responded by creating a separate, higher pay scale for faculty in areas where there is strong competition with industry, such as engineering and business. This has worked to some extent. Many have proposed attracting more graduate students by increasing stipends, using as a rule of thumb that stipends should be at least one-half starting salaries for college graduates. (Some faculty salaries may begin to pale in comparison.)

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78. Georgine M. Pion and Mark W. Lipsey, 'Psychology and Society: The Challenge of Change,' *American Psychologist*, vol. 39, No. 7, July 1984, pp. 739-754; and Ann Howard et al., American Psychological Association, "The Changing Face of American Psychology: A Report From the Committee on Employment and Human Resources," unpublished manuscript, 1986.

In 1986, a time when faculty shortages were still widespread/high but easing, engineering departments were asked to identify the main factors limiting Ph.D. production in engineering (see table 3-12).[79] The one response cited by nearly all respondents was "insufficient funding for graduate student support." Nearly 40 percent of department chairs ranked this as the most important factor.

THE FUTURE OF THE UNIVERSITY: A STEADY STATE ERA?

Graduate education is embedded in the research community and the research university infrastructure. External trends in the global economy, national defense, and competitiveness are changing the Nation's posture toward R&D and the missions of the research universities. In turn, this is affecting graduate education. The changing environment of the research university not only affects supply and demand, but also has reduced the appeal of a university research and teaching career for young scientists or engineers.

Despite the Federal Government's vigorous commitment to basic research, support for defense projects and industrial R&D has grown at the research universities. Economic pressures are forging new research links between university and industry.[80] Many States have devised programs to leverage universities as pivotal actors in research-fueled regional development. And expansion of students, faculty, and research has plateaued.

University research and graduate training can be characterized as a transition to a steady state of Federal funding, increasing competition for resources, and restructuring in the search for new sources of support and new missions. Grant competition and pressures for accountability are increasing the administrative burden on scientists in universities while diverting them from research. The upshot is that the attractiveness of an academic research career has waned from its peak of two decades ago.[81]

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79. Paul Doigan and Mack Gilkeson, "ASEE Survey of Engineering Faculty & Graduate Students: Fall 1985," *Engineering Education*, October 1986, pp. 54-55. The survey of 180 major engineering departments was one in a series of regular surveys conducted by the American Society for Engineering Education.
80. Dorothy Nelkin and Richard Nelson, "Commentary: University-Industry Alliances," *Science, Technology, & Human Values*, vol. 12, winter 1987, pp. 65-74. Such alliances, however, have along history. See Roger L. Geiger, "Milking the Sacred Cow: Research and the Quest for Useful Knowledge in the American University Since 1920, " Science, Technology, & Human *Values*, vol. 13, summer & autumn 1988, pp. 332-348.
81. John Ziman, *Science in a 'Steady State': The Research System in Transition*

Table 3-12. — Factors Limiting Engineering Ph.D. Production:
A Survey of Engineering Departments, 1986

	Percent of faculty citing that factor as 1st or 2nd most important	
	1st	2nd
Insufficient funding for graduate student support	38	35
Insufficient number of qualified students	33	16
Limitation on size of graduate stipends	14	28
Insufficient facilities and space	14	16
Insufficient qualified faculty	0	4
Other	1	1

SOURCE: American Society for Engineering Education Survey of Engineering Faculty and Graduate Students, fall 1985, reported in *Engineering Education,* October 1986, p. 55.

Writing in 1977 about the physical and intellectual infrastructure of the research university, Smith and Karlesky observed that:

> . . . young investigators must work in a far less encouraging research environment than the expansive one enjoyed by their counterparts a decade ago. Flexible funds are not so readily available; in the physical sciences fewer graduate students are around to assist in research; universities are less able to provide start-up funds; and the competition for external grants has intensified. More demanding tenure standards have created obvious pressures of their own. It is unquestionably much more difficult for the young to establish themselves now than it was 10 years ago, but this is a result of the steady state environment for research. . . .[82]

In 1968 Harvey Brooks warned of the implications of the impending slowdown in exponentially growing Federal academic support:

> If academic research budgets continue to level off, grave questions of policy will be posed. 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 and replace outmoded equipment. . . . In the absence of new funding, it will be necessary to invent new mechanisms of funding which will permit greater concentration and specialization of effort. . . . 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.[83]

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82. Bruce L.R. Smith and Joseph J. Karlesky, The State *of Academic Science: The Universities in the Nation's Research Effort (New* York, NY: Change Magazine Press, 1977), p. 183. Also see John Ziman's review of this book, 'Bounded Science," *Minerva,* vol. 16, 1978. pp. 327-339. With the benefit of another decade of hindsight, one might observe that the thunderous Federal support of universities in the 1960s was an aberration. 'Current university practices, orientation, and leadership were all formed during the 60s. The current challenge is to put academic science and engineering back on a realistic slow growth path." Christopher Hill, Congressional Research Service, personal communication, November 1988.
83. Harvey Brooks, "The Future Growthof Academic Research: Criteria and Needs," *Science Policy and the University,* Harold Orlans (cd.) (Washington, DC: Brookings Institution, 1968), pp. 75-76.

Universities are searching for ways to maintain the viability of the research enterprise.[84] Brooks' prescience reveals in two ways the dilemma of science in the steady state: the growing uncertainties and fluctuations of Federal patronage that created a research system it can no longer sustain, and a selective infusion of industrial and State patronage and congressional earmarking on campus that, in the absence of a system for establishing research priorities, fortifies certain research agendas while starving others.[85]

No matter what the research objectives for the 1990s are, they will not be attainable without a qualified human resource base for doing science and technology. The difficulty of the Federal Government and institutions of higher education in ensuring long-term research support creates instabilities in the supply of science and engineering Ph.D.s.[86] David Hamburg has observed that:

> . . . the Federal Government was a major actor in the creation of the "bulge" in academic R&D in the 1960s whose effects persist to this day. Federal

84. Don I. Phillips and Benjamin S.P. Shen (eds.), Research *in the Age of the Steady-State University,* American Association for the Advancement of Science Selected Symposium 60 (Boulder, CO: Westview Press, 1982).
85. Some observers bemoan this as a problem of selecting between big (superconducting supercollider, space station, human genome mapping) and little science; others see the problem as defense v. civilian R&D; and still others warn of "fashionable" research that is either profitable or vital for U.S. economic competitiveness (biotechnology, superconductivity, advanced materials). A framework for weighing alternatives, making choices, and plugging them into the political process has been lacking. Lacking as well, however, is the discretionary budget for supporting all intellectually and economically promising R&D. For recent attempts to construct a framework, see National Academy of Sciences, *Federal Science and Technology Budget Priorities: New Perspectives and Procedures* (Washington, DC: National Academy Press, 1988); Frank H.T. Rhodes, "A System to Set Science Priorities," *Technology Review,* November/December 1988, pp. 21-22, 25; and John A. Dutton and Lawson Crowe, "setting Priorities Among Scientific Initiatives," *American Scientist,* vol. 76, November-December 1988, pp. 599-603. For an approach that favors the proclivities of a sitting president (and a strong science advisor), see Edwin Diamond and Norman Sandier, "Science, Technology, and the Next President, " *Issues in Science & Technology,* vol. 4, fall 1988, pp. 56-61.
86. Lewis C. Solmon and William Zumeta, "U.S. Science Manpower and R&D Capacity: New Problems on the Horizon," *Policy Controversies in Higher Education,* Samuel K. Gove and Thomas M. Stauffer (eds.) (New York, NY: Greenwood Press, 1986), p. 208. For a European perspective, see R.J. Cavanagh, *Workshop on Assessing the Availability and Need for Research Manpower: Activities in OECD Countries — Preliminary Report* (Paris, France: Organisation for Economic Cooperation and Development, Directorate for Science, Technology and Industry, Sept. 2, 1988).

> policy can and does have major shaping effects, positive and negative. . . . It seems reasonable that since the Federal Government has been a major beneficiary of the build-up it should also share in attempting to ameliorate the negative effects of the build-up distortions.[87]

In this transition era, graduate institutions that sustain the dual missions of graduate teaching and research must confront numerous questions, or become beleaguered by unyielding demands and insufficient resources.[88] How does the financing of research affect the environment in which the next generation of researchers is being trained? How do the pressures and perquisites of sponsors alter the relations between faculty and students, between research and teaching, between career expectations and opportunities? If faculty roles now include entrepreneurship, does this imply that apprentice-researchers to these faculty-mentors tend to be oriented to nonacademic employment?

There is currently great pressure for industry collaborative and center-based work at universities. There is also a great deal of concern about such relationships from those who fear that education would wither under the pressures of capitalism and that students would be exploited for financial gain.[89]

The pressure for increased collaboration emanates from government leaders, big industry, NSF, and the management of large research universities who feel that university and industry competencies are diverging, given the "evidence" of problems with U.S. manufacturing, the growing prowess of Japan, and the perceived need for researchers and curriculum to be more "relevant." A more subtle pressure derives from suspicions — inside universities and out — that the traditional disciplines are no longer fertile and should give way to interdisciplinary R&D and more "real-world" work.

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87. Hamburg, op. cit., footnote 3, pp. 29-30.
88. "[W]e are creating two faculties: one devoted to bringing in research grants and publishing as many papers as possible, and the other relegated to handling the teaching load. . . . Many professors will retire in the next decade or so. And when this happens, replacements of quality and dedication will be tough to find as their mission becomes even less prestigious." Douglas E. Kelly, "We are Eroding the Vital Link Between Academic Research and Education," The *Scientist, Oct. 17, 1988, pp. 9-10.*
89. For example, Martin Kenney, *Biotechnology: The University-Industrial Complex* (New Haven, CT: Yale University Press, 1986). Survey responses from graduate and postdoctoral students (who of necessity tend to minimize professional cognitive dissonance) suggest that this concern is overstated. See Michael E. Gluck et al., University-Industry Relationships in the Life Sciences: Implications for Students and Post-Doctoral Fellows," ***Research Policy,*** vol. 16, 1987, pp. 327-336.

Little is as yet known about the educational impacts of large research centers and more pervasive university-industry collaborations. All accounts stress the educational function of centers, but few specifics are available. For example, the Semiconductor Research Corp. is developing a curriculum in microelectronics manufacturing for engineering students with Florida State University and Florida A&M University.[90] Given the uncertainty surrounding the impacts of collaborations, perhaps the best policy is to emphasize concern for education, and continued monitoring.

Some hoped-for benefits of closer industry-university contacts are:

- the ability of industry to find the best talent as soon as possible;
- more "relevant" and "real-world" education in those areas that need more relevant engineering (e.g., combustion);
- the ability for students to work in a multidisciplinary center that cuts across departments;
- the opportunity to work with people in teams (this must be something of a myth, because faculty-based work often has several investigators and, in any case, always contains some teamwork);
- a reduction in the government and university burden of support of students; and
- more undergraduate participation in research.

Some feared impacts are:

- the siphoning off of students who would continue on for the Ph. D.;
- the increased secrecy and "ownership" of information; and
- the arrival of the profit ethic on campus, changing the ethos of university education.

Evidence from historical and contemporary case studies, while not conclusive, suggests that specific fields and the research university as a whole cope well with new research missions (see boxes 3-G and 3-H).

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90. Ralph K. Cavin III and D. Howard Phillips, "SRC: A Model of Industry-University Cooperation," *Engineering Education,* vol. 78, January 1988, p. 227.

The Future Supply of Ph.D.s

The future supply of Ph.D.s is a matter of quality as well as of numbers. Many fear that higher-paying occupations will attract more of the most talented students, as graduate study and academic careers, salaries, and lifestyle become relatively less attractive.[91] Assistant professorships at colleges and universities Continue to Provide the lowest salaries.[92]

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.[93] As for quality, at the margins talent can be lured or discouraged to relieve shortages and surpluses. The well-documented elasticity at the baccalaureate level does not hold as readily at the doctoral level.[94]

The academic job market is not as attractive as it used to be, even in the post-golden age of the 1970s. Faculty-investigators weaned on "safe" Federal funding must seek new strategies to ensure continuity in their research programs and teams. Time-consuming and relentless competition for research funds coupled with uncertainty over future funding deter students from pursuing Ph.D.s, and then deter new Ph.D.s from seeking academic careers.[95] Well-funded, well-salaried, stable positions in well-equipped industry research laboratories appear more and more attractive. As more industry goes "high-tech," researchers are attracted by good equipment and working conditions, and the advantages of university life dwindle.[96]

91. Solmon and Zumeta, op. cit., footnote 86, pp. 193-194.
92. Eleanor L. Babco, *Salaries of Scientists, Engineers and Technicians: A Summary of Salary Surveys,* 13th ed. (Washington, DC: Commission on Professionals in Science and Technology, 1987).
93. Allan M. Cartter, "Scientific Manpower for 1970 -1985," Science, vol. 172, Apr. 9, 1971, p. 139.
94. Richard Freeman, "Supply and Salary Adjustments to the Changing Science Manpower Market: Physics, 1948-1973," American *Economic Review,* vol. 65, March 1975, pp. 27-39.
95. National Science Foundation, "Recent Doctorate Faculty More Actively Seeking Research Support," *Mosaic,* vol. 18, winter 1987/88, back page.
96. Hill offers an alternative "autonomy" hypothesis: In the "golden age," university faculty positions offered the greatest autonomy; in this new era of venture capital, a more lucrative (and risky) route to autonomy is the small, start-up high-technology firm. There, he says, "you'll find the 'lost faculty'." Christopher Hill, Congressional Research Service, personal communication, November 1988.

Universities are in a vulnerable position. Faculty retirements are expected to rise significantly in the 1990s. Foreign citizens are routinely recruited to faculty appointments in engineering and mathematics. So, too, are racial and ethnic minority Ph.D.s. But their numbers in the pipeline are still small, so academic departments compete for a scarce resource.[97] The current tenure glut that forced universities to create nontenure track positions will be relieved somewhat by faculty retirement.[98] Universities are avoiding swelling their permanent faculty ranks, mimicking a trend toward temporary and contract hiring in corporations. Instead of filling vacated positions with new full-time tenured and tenurable faculty, a dual-track ladder of temporary full- and part-time researchers and teachers may develop. This new set of positions would reflect employers' demand for an elastic academic work force, one that expands and contracts with the waxing and waning of Federal and industrial research priorities.

One way universities cope is by specializing and concentrating resources. Few research universities, 50 to 100 according to different criteria, have the resources to maintain a breadth of research programs across the spectrum of science and engineering fields. For 250 other Ph.D.-granting institutions to try to emulate the formula and success of the 100 would be challenging and costly. The Federal Government is the dominant source of revenue for research universities. There is a sense that, since R&D funding and good faculty are limited, improving one university must to some extent come at the expense of another (unless an infusion of industrial or other expenditures occurs). This tradeoff was perceived almost two decades ago:

> . .. it is urgently necessary for the Federal Government to identify a category of "national universities)" perhaps 75 to 100 in number, and guarantee certain minimum support levels for graduate education, research, and student aid. If the task of identifying institutions is too difficult, or too

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97. Shirley Vining Brown, Increasing Minority *Faculty: An Elusive Goal, A* Research Report of the Minority Graduate Education Project (Princeton, NJ: Educational Testing Service, 1988). The obvious long-term goal is to expand the resource; trading scarce talent — regardless of sex, race, **ethnicity,** or physical handicap — across sectors and fields will not satisfy the need. The **"new demographics"** make this painfully clear. See Office of Technology Assessment, op. cit., footnote 30, pp. 7-13; and *Manpower Comments,* October **1988,** pp. 14-21.
98. The **"relief,"** according to some, will be profound and problematic. See Carol **Boyd** Leon, "Good-bye, Mr. Chips: Get Ready for a Shortage of College Professors," American Demographics, October 1988, pp. 332-35.

politically explosive, then a workable alternative might be to select 50 to 75 departments from each of the major disciplines, with Federal support going only to the most eminent or promising fields of the study in any single institution. . . . [T]he failure to develop a more effective and rational system of support of graduate and professional education is likely to dangerously erode the greatest achievements of American higher education.[99]

The vast majority of scientists in a recent national survey disagreed with a policy of spreading cuts evenly across all universities.[100] Targeting the most Ph.D.-productive research universities for sustained support is the surest way of ensuring the flow of fresh talent into the research work force.[101]

One approach to creating academic posts and making academic life more appealing is the U.S. Presidential Young Investigator program, which bestows prestige and several years of generous funding upon young faculty. Several European nations, facing the same situation, have implemented similar programs (see box 3-I).

Lessons From the Golden Age

The energetic Federal build-up of graduate education in the golden age of the 1960s enhanced research, education, and the research work force, but left a legacy of

99. Cartter, op. cit., footnote 93, p. 139.
100. Sigma Xi, A New Agenda for Science (New Haven, CT: 1987), pp. 22-24. Seventy percent disagreed with the statement: "During periods of retrenchment of Federal support of research a desirable policy is to distribute the cuts across the board on a flat percentage basis, thereby to spread the pain evenly." The survey was of Sigma Xi members — a selective, rather than representative, sample of U.S. university faculty. For an historical perspective, see David W. Breneman, *Graduate School Adjustments to the "New Depression" in Higher Education*, Technical Report No. 3 (Washington, DC: National Board on Graduate Education, February 1975), pp. 24-27, 30-35.
101. Harvey Brooks, "The Research University: Doing Good, and Doing It Better," *Issues in Science and Technology*, vol. 4, winter 1988, pp. 49-55. A 5-year national Projector Research on Doctoral Education, in progress at the University of Rochester, is examining student financing methods, among other aspects of graduate education. The project is conducted under the auspices of the Association of Graduate Schools in the Association of American Universities and sponsored by the 46 participating institutions and grants from the Pew, Mellon and Lilly foundations. Findings of this project may inform the perspectives of the two camps and the higher education investment strategy of the Federal Government.

overexpanded departments, and abruptly curtailed careers as young Ph.D.s and graduate students adjusted to the unanticipated and severe cutback in Federal support.

Snyder offers several lessons from this Federal build-up and its ramifications.[102] Many echo the themes of this chapter:

1. Federal policies should take into account market forces and their synergistic interaction with Federal programs; State, institutional, industry, and Federal R&D spending changes all increase education and research support.
2. It takes at least 4 and, on average, closer to 7 years to produce a Ph.D. Therefore, the effects of graduate education policies may not be evident for several years; in the 1960s, by the time a Ph.D. surplus became apparent, Ph.D. production was still increasing rapidly and there were still large numbers of unsuspecting graduate students in the pipeline. Earlier tapering off of support would have been better.
3. Heed demographic trends; in the 1960s, there was a demographically driven slowdown in undergraduate enrollments and a federally mandated acceleration of opportunities to acquire a higher education.
4. Supply and demand projections are easy to overinterpret and use improperly, but keep working at them.
5. Federal agencies should take the level of RAs into account in setting levels of fellowship and traineeship support.
6. If programs are supposed to provide long-term support for core institutions and core talent, ensure that those programs are long term and stable.
7. Carefully consider optimal roles for agencies in institutional, and research and student support. Coordinate programs. System upgrading and institutional development might be more appropriate for NSF, and maybe NIH, while more targeted, research-related programs seem best for the narrower mission agencies such as DOE and NASA.

The legacy of the golden age can be stated as: the science base is only as strong as the investment in people — first and foremost.

102. Snyder, op. cit., footnote 8, pp. 42-44.

Box 3-A. — Letters From Graduate Students

Lloyd Whitman, "Consider Graduate-Student Life," Physics Today, June 1986, p. 41

"The lack of concern for graduate-student life is manifested in many ways . . . an unmarried graduate student supported solely by a teaching or research assistantship lives frugally — after basic living expenses there is little money left over for repairs or extraordinary expenses. Students are particularly concerned that they lack the resources to cope with medical emergencies not fully covered by the nominal student health insurance. Most students agree that graduate school is not the place to start a family, especially considering the fiscal constraints imposed by current stipends. As it typically requires five or six years to complete a Ph. D., most students will be 26-30 years old before having the resources (not to mention the time) to start a family. The sacrifice is greatest for women, who will have spent their safest childbearing years in graduate school only to then have to choose between starting a family and embarking on a career. . . .

"What are the implications of these conditions? For instance, to what extent are qualified undergraduates discouraged from continuing with graduate work in physics? And for those who do continue, do the prospects of financial success influence the choice of research fields? At institutions where support for every student is not readily available, graduate students will be lured to fields that are currently well funded. Similarly, job prospects vary widely by subfield, creating an incentive for students to pursue the 'hot' new areas of research. This situation creates the danger that we will end up with a plethora of experts in currently active research areas, though these will not necessarily be of primary importance in years to come. . . . It may be that students under financial pressure will choose projects that will enable them to finish quickly rather than undertaking the projects for which they have the most enthusiasm. Lastly, one might consider whether the conditions of graduate life are conducive to the most productive graduate work. One hopes that students do not become so discouraged that their work is affected."

V. Chandrasekhar, "A Foreign Graduate Student Speaks Out," Engineering Education, April 1988, p. 666.

"First, some faculty are clearly looking for bargains in their research assistants (much like a coach in a "revenue sport" may look at an incoming student athlete). These faculty let the work aspect of the relationship (i.e., the fact that they pay about $350/month to their graduate assistants) completely corrupt the educational aspects. . . .

"The faculty members' desire to get the best bang for their buck results in their making inordinate demands in terms of the amount and quality of research work required, the rate of results, and the amount of support work expected . . . forgetting that a novice is at work, they may make demands for rapid results, as is done in industry when professionals do the work. They may ask graduate students to "live their thesis" — learn on their own and perform with little help the countless tasks necessary for typical engineering research work (computer programming, glassblowing, machine shop work, electroplating). . . .

"The result is that research assistants are forced to go into a crisis mode of living (similar to what happens in medical residencies). This is an important reason why not many qualified American students are interested in graduate study."

Box 3-B.— National Defense Education Act Trainees

From 1964 to 1973, the National Aeronautics and Space Administration (NASA) supported several thousand predoctoral trainees in a broad array of fields under Title IV of the National Defense Education Act (NDEA)[1] At that time, with Sputnik and the rapid space build-up, NASA'S projected personnel needs were great and spurred direct NASA support of Ph.D. training. A 1961 report reflects the policy mentality of the times:

> NASA'S needs in research appear certain to build up to a significant percentage of the total scientific research of the U.S. . . . The most direct way for NASA to assure itself of an adequate supply of Ph.D.s for its own position in research and administration, and for its contractors both in the universities and industry, would be to provide traineeships and fellowships for advanced students in the space-science fields and closely related sciences.[2]

So the NDEA traineeship program was born.

A study of the careers of NASA trainees who earned Ph.D.s is currently being conducted, looking at how trainees' careers developed and diverged for the 20-odd years following their traineeship.[3] Results from a pilot survey indicate that most trainees had been interested in science or engineering from an early age, and had chosen their field in high school or college. For these scientists the NDEA traineeships were more an

1. The main purpose of the National Defense Education Act (NDEA) Title IV was ". . . to alleviate an existing and projected shortage of qualified college teachers." The National Aeronautics and Space Administration-supported fellows were but a portion of the NDEA program. The early history of NDEA is discussed in Clarence B. Lindquist, NDEA Fellowships for *College Teaching,* OE-55058 (Washington, DC: U.S. Department of Health, Education, and Welfare, 1971); and Laure M. Sharp, *Study of NDEA Title IV Fellowship Program, Phase I* (Washington, DC: Bureau of Social Science Research, Inc., March 1968).
2. The National Aeronautics and Space Administration, *Working Group Report on NASA-University Relations* (Washington, DC: August 1961).
3. The National Aeronautics and Space Administration (NASA) is supporting a survey of National Defense Education Act (NDEA) fellows, conducted out of the Space Policy Institute and Science, Technology, and Public Policy Program of the George Washington University, Washington, DC. About 4,000 NDEA/NASA-sponsored Ph.D. recipients will be surveyed in fall 1988. Most trainees were in the physical sciences or engineering. The survey is looking at influences on career choice, impacts of NDEA fellowships, and career patterns. See Jeffrey D. Rosendhal and Thomas Dietz, George Washington University, "The NASA Predoctoral Trainees of the 1960s: Where Are They Now and What Are They Doing?" unpublished interim report, June 1988.

additional and welcome source of money rather than a direct and immediate career lure. However, the NDEA program was part of a broad national endeavor in space, science, and higher education. Its impacts reached deep into the school system; many children were "turned on" to science by Sputnik and the widely-publicized NASA missions of the day.

Nearly all the Ph.D.s trained under the NDEA traineeships remained in science and engineering, and a surprisingly large fraction, over two-thirds, work in their Ph.D. field today. NDEA also supported students in broad areas of science only vaguely related to space. While it is impossible to compare the effects of NDEA training grants to other training grants or other forms of support, the preliminary conclusion of the study is that NDEA traineeships helped create a scientifically productive cadre of career scientists and engineers of great and lasting value to society (although not focused, as was intended, on space science).

NASA successfully spread training grants throughout all 50 States, and to institutions that had not been big recipients or Ph.D.-producers. Justification was that the top 20 were "saturated" in Ph.D. production. With this policy, the NDEA programs successfully broadened the university base for Ph.D. production.

Little long-term information is available on NDEA trainees who did not complete a Ph.D. One study of all 45,000 NDEA fellows showed that about 60 percent of the early fellows had achieved Ph.D.s. by 1974.[4]

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4. Lindsey R. Harmon, Commission on Human Resources, National Research Council, Career Achievements of NDEA (Title IV) Fellows of 1959-1973, Report to the U.S. Office of Education (Washington, DC: National Academy of Sciences, 1977), pp. 6-7, 10, 14-15. Fellows in the natural sciences and education had higher completion rates than social sciences and humanities fellows. In all fields, NDEA fellows completed their degree much faster than the average Ph. D., in some fields several years faster (based on elapsed time from receipt of B.S. to receipt of Ph.D.).

Box 3-c. — Women in Science and Engineering: Graduate Study and Financial Aid

Are women science or engineering students less likely to receive financial aid than men? The answer is yes. Several factors, however, cloud the situation.

First, women cluster in different fields of study than men; they are more likely to be in the social and biological sciences, and less likely to be in engineering and the physical sciences. Many forms of aid, particularly research assistantships, fellowships, and traineeships, are linked to field of study. As women tend to major in fields where less of such aid is available, they are less likely than men — averaging across all science and engineering fields — to receive financial aid.

So a better question is: Are women in, for example, physics or economics, less likely to receive aid than men in the same field? The answer is still yes. The reasons are even more subtle and complex, however, at this level of analysis. Many factors contribute to women getting less aid:

- They are more likely to be attending graduate school part time, both overall and compared to men in the same field. For some this may in part be due to family responsibilities, such as the need to care for young children or help support a husband.
- They do not fare as well as men in receiving the more desirable forms of financial aid, such as fellowships, traineeships, and research assistantships (RAs). Within any given field, women are less likely to receive RAs.
- They are likely to be supporting themselves. This continues a pattern observed in undergraduates: Women are less likely to receive grants, loans, or earnings from part-time jobs. The pattern continues when they enter the work force.[1]

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1. The National Science Foundation 1986 New Entrants survey of recent college graduates shows that women employed full time in science or engineering earn 20 percent less than their male counterparts. Salary differentials vary by field; in engineering, men and women take home the same paycheck, while in the social sciences the salary differential is more than 20 percent. National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1986,* NSF 87-321 (Washington, DC: 1987), p. 82.

A similar message comes from a different source. The U.S. Department of

Finally, while some financial aid is better than none, some forms are more valuable, in the sense of professional culture and career, than others:

> A research assistantship contributes to the quality of graduate education. It serves to integrate the student into the profession. It serves to teach him or her the sort of nontechnical elements of the profession. You learn how the grant mechanisms work. You become in the sciences, in a very important way, integrated into research groups, which no other form of support provides. So we see rather gradually, insidiously, differentiation taking place where women are expected to do a disproportionately higher share of undergraduate teaching, which takes them away from the company of their colleagues and faculty and puts them into a different environment with young students, while male students are working with faculty and regarded as colleagues. . . . They are likely to have more opportunities to publish before they actually finish their Ph.D.s. They are likely to have subsidized travel, attend meetings, have opportunities to be introduced to people in other institutions. . . .[2]

Education 1985 Recent College Graduate (RCG) Survey shows an overall 14 percent salary advantage for men employed full time in science and engineering about 1 year after graduation (3 percent in engineering, 16 percent in computer specialties, 23 percent in the natural sciences, and 43 percent in the social sciences). (For all professional occupations, RCG data show men to have a 35 percent salary advantage. Some of the salary difference may be due to the kinds of jobs women take, which is related to the jobs they are of fered.) U.S. Department of Education, unpublished data.

2. Lilli Hornig, Wellesley College, testimony, 1983, cited in Mary Moran, *Student Financial Aid and Women: Equity Dilemma?* (Washington, DC: ASHE-ERIC Higher Education Reports, 1986), pp. 27-28. Also see Fred M. Hechinger, "About Education: When Motherhood Interferes With the Training of Young Female Scientists," New *York Times*, *Nov.* 9, 1988, p. B11.

Box 3-D. — Women in Higher Education:
Making an Institutional and Societal Commitment

The issues facing women studying and considering scientific careers derive mainly from the larger social and economic situation for women. Improving the participation of women in science and engineering requires addressing some of the larger issues about treatment of women in education, the workplace, and society at large.

Although women have made a great deal of progress, they still face many barriers. There is no one magic fix. Vigorous action on many fronts is required, supported by broad, sustained national commitment to equitable education and employment opportunities for all. A special report of the American Council on Education suggested that colleges and universities:[1]

- Seek strong commitment from the leadership of the institutions to understand and address the concerns of women students, faculty, staff, and administrators;
- Correct inequities in hiring, promotion, tenure, and salary of women faculty, administrators, and staff;
- Provide a supportive campus climate for women;
- Make a permanent institutional commitment to women's studies;
- Review all policies for effect on majority and minority women;
- Integrate impact studies into planning;
- Give specific attention to sexual harassment;
- Prepare an annual status report;

1. American Council on Education, *The New Agenda of Women for Higher Education: A Report of the ACE Commission on Women in Higher Education* (Washington, DC: n.d.).

- Initiate a campus values inventory;

- Develop an institution-wide concern for children and families;

- Appreciate the value of diversity;

- Make leadership development, and commitment to fostering women's leadership, joint priorities;

- Establisher reaffirm the commitment to a Commission on Women;

- Appoint a high-level person whose formal responsibilities include advocacy for women on campus; and

- Create a center for the exploration of community and personal relationships.

Box 3-E. — Institutional Support and Graduate Education

The rapid growth in Federal support of R&D and graduate education in the 1960s brought with it concern over the ability of U.S. universities to provide quality research and training during this expansion.[1] In response, Federal programs were established to improve and expand university infrastructure, apart from support of academic research and students. These institutional development programs had two broad aims: to improve the quality and capacity of well-established departments, with flexible funding for equipment, facilities, libraries, faculty, and other personnel; and to expand the number of high-quality departments by investing in "second-tier" institutions.

During this period, the National Science Foundation (NSF) funded three major institutional support and development programs, providing money for equipment, facilities, and faculty:

NSF Institutional Support Programs	Total $ millions (current dollars)	No. Instit.
Graduate Science Facilities (1960-1970)	$188	182
Science Development (1965-1972)	$233	104
Institutional Grants for Science (1961-1972)	$120	939
TOTAL	$541 (or $1,760 in 1987) constant dollars)	

According to one evaluation, these programs achieved their goals, with modest improvement of many departments and substantial, lasting improvement at a few institutions.[2]

1. Another significant portion of Federal support of educational institutions has been targeted to undergraduate education, to a large extent historically Black institutions and to a lesser extent predominantly undergraduate institutions. They are not discussed here, but they continue to figure significantly in Federal priorities. Federal institutional support of land-grant institutions, under the Merrill Acts of 1862 and 1890, by ensuring wide geographical distribution of resources, has also influenced science and engineering education.
2. National Science Foundation, "Institutional Support Programs at the National Science Foundation, 1960 -1972," PRA Issue Paper 84-26, May 21, 1984.

Graduate Science Facilities provided funds for facility renovation, repair, and construction at universities offering doctorate or master's degrees. Its 50 percent matching requirement successfully brought in State and private contributions for facilities. The goal of Institutional Grants for Science was to strengthen the research capability of existing high-quality institutions by providing discretionary funds, which universities spent on equipment, supplies, facilities, and personnel. Science Development was designed to increase the number of top-flight research universities. The Science Development program was the only one of these three NSF programs that was evaluated formally.

The NSF Science Development Program (SD) provided generous institutional development funds in the late 1960s to strong "second-tier" universities to nurture new centers of research excellence.[3] It was the first large-scale Federal venture into institutional development. The program began in 1965 and was terminated in 1972.

While the amount of SD money was large, it was still a small increment (15 to 20 percent) on top of a larger base of Federal funding to those institutions. The core of SD was University Science Development (USD), which awarded $177 million in flexible institutional grants to 31 public and private universities over 6 years (a little over $500 million in 1987 dollars). Typically four to five departments were built into each grant proposal. The grants ran for 3 years, with a potential 2-year supplement. NSF's decision process included site visits and peer review by university administration experts as well as scientists. Recipients were selected in part for geographic equity; USD money helped start Research Triangle Park in North Carolina. The average grant was about $6 million, spread over several years. Matching of State, private, and institutional funds was not mandated but was an important part of the program.

SD funds were described by recipients as catalytic, accelerating improvement and expansion and making possible ventures and facilities that otherwise would not have been

3. This summary is based on a National Science Foundation-commissioned evaluation of the Science Development program: David E. Drew, *Science Development: An Evacuation Study,* a technical report presented to the National Board on Graduate Education (Washington, DC: National Academy Press, June 1975); and National Board on Graduate Education, *Science Development,* University *Development, and the Federal Government,* Report Number Four (Washington, DC: National Academy of Sciences, June 1975).

possible. SD succeeded at its two major goals, lasting improvement in institutions and widened geographic distribution of funds. NSF was lauded for making good selections and for hands-off administration.

The effect of USD was more apparent at public than at private institutions. Drew hypothesized that private institutions used the money to maintain all departments rather than expand in the financial retrenchment of the early 1970s. In terms of increasing faculty publication productivity and Ph.D. production, SD funds also had the greatest effect on less affluent institutions, where they represented a greater share of the budget.

Box 3-F. — Academic Marginals

In recent years the number of available faculty positions in universities has been far smaller than the number of new doctoral scientists.[1] Slowly growing faculty employment is not enough to take up the slack. Part of the surplus was once absorbed into postdoctoral fellowships that were extended until more suitable jobs became available. In the basic biomedical sciences, for example, the number of postdoctoral grew rapidly from 1974 through 1982, then leveled off, although the number of Ph.D.s awarded in those years grew very slightly.[2]

Many of these Ph.D.s have been directed into positions at the margin of the university. Variously termed "the unfaculty," 'unequal peers;" and "the nonfaculty,"[3] these scientists populate an academic "never-never land" made possible by and especially vulnerable to the availability of research support. Bearing such titles as 'Assistant Research Anatomist," "Research Associate," or "Research Fellow," these scientists typically do not share the academic rights and privileges of their counterparts on the regular tenure-track faculty and typically earn lower salaries. In a few institutions, there is a well-defined career track outside the usual academic ranks for these people, so it is possible to attain the rank of full professor (or its equivalent), although usually without tenure.[4] Many are employed not by university departments, but by quasi-independent research units.

The number of marginal scientists has grown rapidly in recent years. According to National Research Council data, academic employment for doctoral scientists in nonfaculty positions (other than postdoctorates) grew at an annual rate of 7.8 percent between 1973 and 1979; in contrast, faculty employment grew 4.1 percent during that period.[5] Growth in nonfaculty positions has continued at an annual 7 percent 'ate into

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1. National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981); and Don Phillips and Benjamin Shen (eds.), Research in the Age *of the Steady-State University* (Boulder, CO: Westview, 1982).
2. Institute of Medicine, *Personnel Needs and Training for Biomedical* and Behavioral *Research* (Washington, DC: National Academy Press, 1985), p. 56.
3. Clark Kerr, *The Uses of the University (New* York, NY: Harper and ROw, 1963); Carlos Kruytbosch and Sheldon Messinger, "Unequal Peers: The Situation of Researchers at Berkeley," *American* Behavioral Scientist, VOL 11, May-June 1968, pp. 33-44; and Albert H. Teich, "Research Centers and Non-Faculty Researchers: A New Academic Role," Phillips and Shen, op. cit., footnote 1, pp. 91-108.
4. Kruytbosch and Messinger, op. cit., footnote 3; Teich, op. cit., footnote 3.
5. National Research Council, op. cit., footnote 1, p. 69.

the 1980s, although it has slowed in 1986 (the last year for which there is published data).[6]

The growth of marginal positions (and the organized research units that often employ them) signals a change in university structure driven by environmental uncertainties, new obligations to industrial patrons, and tension between educational and research values. Just the sheer capital investment in research and development requires highly-skilled full-time staff to maintain operations. Universities' initial responses to reductions in research support have been to reduce costs, operate more efficiently, and secure as much flexibility as possible so that shrinkage, if necessary, will be both possible and less painful. Marginal positions and research units give universities flexibility in personnel and administration that traditional faculty positions and department structures do not permit. Simply put, marginal positions are more readily emptied and reallocated than are tenured and tenure-track faculty, and research units are easier to dissolve than departments. This buffer of temporary workers follows a trend in the private sector toward hiring more in-house contractors and short-term employees. Universities are also building bridges to alternate sources of funding, such as industry and State government, in particular by targeting research projects and centers to industry and State interests.

Despite the apparently sound reasons for increasing the ranks of marginal scientists, these positions affect the career prospects of incumbents, the scientific research that they do, and ultimately the academic work force. Marginal scientists are a significant scientific resource. The importance of their research can be documented from their publication and citation records. Moreover, the work done in these marginal positions also contributes to the productivity of other scientists and indirectly assists academic search committees by providing a longer "track record" with which to evaluate job candidates. But their time in these marginal positions also has costs.[7]

For example, there is no job security: employment usually ends when a project ends. Such positions have limited academic "rights," such as claims on laboratory and office space or access to seed money and equipment. Within the university, marginal scientists are dependent on others to provide part-time teaching or research employment to complete their salaries, to gain access to equipment, and thus are indebted to those who bestow such favors. In relations with the larger scientific community, occupants of

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6. National Science Foundation, Academic *Science/Engineering: Graduate Enrollment and Support, Fall 1986,* NSF 88-307 (Washington, DC: 1988), p. 188.
7. Edward J. Hackett, "Science in the Steady State: The Changing Research University and Federal Funding," OTA contractor report, 1987.

marginal positions are at a competitive disadvantage because they do not have an established laboratory. Overall, such positions have relatively poor career prospects. Some who choose to remain are driven out as "too senior" to occupy such posts.

Marginal positions are an extension of the scientific apprenticeship system. But the appeal of flexible graduate education and postdoctoral training may lose its charm as a "Permanent" marginal role. As a hybrid of the German *privatdocent* and the English fellowship, the marginal position encourages scientists to acquire new skills, prove themselves, and seek faculty openings. As a creature of Federal research support, marginal positions redirect scientists' careers in ways that diminish both professional autonomy and rewards. From both an institutional and Federal perspective, however, marginals represent a convenient hedge against both the squeeze of faculty tenure and retirements. Better understanding of this journeyman Ph.D. talent pool is needed.

Box 3-G. — Impact of a Federal Research Mission: The Apollo Program

The Apollo program is a widely acknowledged example of a Federal research mission that succeeded in quickly marshaling and developing the scientific and engineering resources needed to achieve a national goal. During the early-1960s National Aeronautics and Space Administration (NASA) recruited staff for the agency; pressured its contractors to recruit the technical people who would prove indispensable as systems engineers, project managers, and support personnel; and through a well-publicized grant program, supported university research in all 50 States.[1]

But NASA did not—and probably could not—have anticipated all the long-term consequences of its recruitment policies. NASA officials accepted the conclusion of the Gilliland Report (so named for its chairman) that the Nation faced a shortage of scientists and engineers by 1970, only to discover 4 years later that they were contributing to a surplus of technical people that the economy could no longer absorb. By then, NASA was faced with the need to start trimming its own work force. And here the agency failed to make the orderly transition to the post-Apollo period that Director Webb and his associates anticipated.[2]

The long-term effects of these separations affected NASA's ability to carry on much of its research, or to plan new flight projects. It was not that the proportion of NASA scientists and engineers to total agency employment declined. Quite the contrary. As a single category, they constituted just over one-half of NASA permanent employees. But there were fewer scientists and engineers engaged in hands-on research. There no longer were as many technicians available to support professional staff; the sharpest decrease in the number of bench-level scientists and engineers was in the age range from 30 to 39—precisely those whose research ideas were most likely to lead to flight projects a decade or more down the road.[3]

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1. Arnold S. Levine, "The Apollo Program: Science and Engineering Personnel Demand Created by a Federal Research Mission," OTA contractor report, 1986; and W. Henry Lambright, *Launching NASA's Sustaining University* Program, Limited Advance Edition (Inter-University Case Program, Inc., 1969).
2. Arnold S. Levine, *Managing NASA in the Apollo* Era (Washington, DC: National Aeronautics and Space Administration, Scientific & Technical Information Branch, 1982), p. 136.
3. This discussion is based on Hans Mark and Arnold Levine, *The Management of Research Institutions — A Look at Government Laboratories* (Washington, DC: National Aeronautics and Space Administration, Scientific & Technical Information Branch, 1984).

Yet Apollo did create research capabilities that outlasted the program that created them. Because Apollo drew on all of NASA's resources, it compelled each center's managers to think of themselves as parts of a much larger organization. During the 1960s the "research" and the "development" centers tended to become more like each other; centers like the Ames and Langley Research Centers, with a mixture of smaller projects, weathered the budget cuts at the end of the decade better than those, like Marshall, with enormous development projects that were winding down. The older National Advisory Committee for Aeronautics centers found themselves with a broad range of skills in aeronautics, life sciences, and spacecraft design, many of them conferred by Apollo.

The impact of Apollo on scientists and engineers employed by NASA contractors was even more complex. Some remained in space-related programs; other moved on to comparable work in the aircraft industry; managers at higher levels moved back and forth between executive positions in industry, NASA, and the Defense Department. On balance, NASA played a stabilizing role in the aerospace industry; as employment on Apollo declined, professionals became available for commercial or defense-related work elsewhere. As for those who were laid off when NASA contracts were completed, the majority soon found comparable work, except among older engineers.[4] "In a fast-moving market, the needs of employers may change by the time entering students graduate."[5] This describes rather well what happened to many of the graduate students that NASA sponsored in the 1960s. Although the unemployment rates for scientists and engineers in the early-1970s was relatively low, they were much higher than they had been only 3 to 4 years earlier — four-and-one-half times as high for engineers.[6]

What are the longer-term implications of Apollo for the management of Federal research missions? Three observations can be made. First, Apollo embodied a certain approach to the management of large-scale endeavors that became very influential. As Webb put it, ". . . it is the new and different way of doing things — of organizing the use of knowledge and technology and human and material resources — rather than the new things themselves that is of most importance. . . ."[7] This implies that projects of such

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pp. 140, 142.
4. Levine, op. cit., footnote 1, 1986.
5. U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force* (Washington, DC: U.S. Government Printing Office, December 1985), p. 25.
6. National Science Foundation, *1972 Manpower Report of the President* (Washington, DC: U.S. Government Printing Office, March 1972), p. 121.

complexity require a new kind of manager: someone with a profound knowledge of the science and technology that the mission demands, with the ability to motivate the government and contractor workers involved. Of necessity, such people are rare.

Problems arise when a style or discipline appropriate to one kind of program is transferred to another. The same management approach — and even many of the same managers — that worked for Apollo was applied to the development of the Space Shuttle. It could certainly be argued that Apollo and the Shuttle were comparable as projects of inordinate complexity and technical difficulty. But for all its sophistication, Apollo was simple and its principles were well understood. No new technology was required in most instances. The Shuttle is far more complex and, until the Challenger tragedy, brought with it problems more like those of a commercial enterprise than of a government agency program. This suggests a second conclusion. Precisely because endeavors such as Apollo, the Space Shuttle, the War on Cancer, and the Strategic Defensive Initiative (SDI) are not routine, it is seldom possible to specify in advance the personnel needs of each one. Apollo was an exceptionally discrete, well-defined program with one main objective and many secondary ones. This is less true of the Space Shuttle or SDI and holds least of all for the War on Cancer.[8] NASA knew when it had achieved the goals of Apollo; comparable criteria of success are still lacking for these other programs.

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7. James E. Webb, Space Age *Management: The Large-Scale Approach* (New York, NY: McGraw-Hill, 1969), p. 61.
8. Kenneth E. Studer and Daryl E. Chubin, *The Cancer Mission: Social Contexts of Biomedical Research* (Beverly Hills, CA: Sage Publications, 1980), ch. 3.

Box 3-H. — Industrial Research on Campus: Effects on Biotechnology Students

One aspect of the "steady state" of academic science is the growing importance of industrial research support. With waning growth in Federal support, industrial values and practices associated with industry funding would seem to portend change in the academic milieu. While changes do occur, they are less dramatic than some have feared.[1]

Industry-sponsored research has grown more important on many American campuses in the past two decades, and particularly during the 1980s. However, industry funds are still a relatively small part of the university research budget. In real dollars, Federal research funding at universities rose 700 percent between 1953 and 1968, and by less than 20 percent in the subsequent 15 years. Meanwhile, beginning in the mid-1970s, American industry entered an expansive phase of research and development. In some cases — notably that of biotechnology — increased industry support included new institutional arrangements with universities, such as the establishment of entire industry-funded laboratories. Today, about 6 percent of university research is paid for by industry (and more in some fields), and this proportion is growing.

This reversal of the longstanding trend in increasing Federal support has disrupted scientists. Some laud the introduction of real-world priorities into academic research and the training of future researchers, particularly in engineering. They believe that subsidized academic scientists and students should tackle the current problems of society and industry.

Others see dangers in these new relationships. They cite risks of graduate students imbibing new, short-term, commercial values. The success of science, this line of argument maintains, involves the pursuit of research topics solely on their scientific merits; a student who is constrained by industrial support may not develop the judgment to identify truly important topics. In addition, some think, industry's emphasis on applied research may damage the traditional academic strength of basic research, and

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1. Michael E. Gluck, "Industrial Support of University Training and Research: Implications for Scientific Training in the 'Steady State'," OTA contractor report, 1987.

proprietary secrecy may inhibit the free exchange of information on which science is thought to thrive.

A survey of 693 life science graduate students and postdoctoral fellows at 6 research universities suggests that the influence of biotechnology firms on graduate students is substantial, but not much more constraining than any other funding influence.[2] The survey indicated that 19 percent of students and fellows surveyed received funds — research or training grants, salaries, or scholarships — directly from industry. Another 15 percent received no direct industry support, but worked under faculty advisors whose research was supported by industry. About 14 percent said their faculty advisors owned stock in biotechnology companies, but only a few of these students received funds from these companies. A separate survey indicated that only 5 percent of biotechnology faculty received more than 60 percent of their research support from industry (a somewhat smaller proportion of faculty than in chemistry or engineering).[3]

The conditions attached to such support are important in determining the influence of industry on the socialization of scientists. Just what is required in return for the funds? Industry funding may restrict research topics, or require students and fellows to work for the firm that supports them. In the extreme, such restrictions could result in a narrower education, with less room for initiative, than is typical in government-supported education.

In practice, some conditions are attached to most funding. There maybe slightly stronger conditions on industry money than those attached to Federal grants, but there is no evidence that such conditions affect the ability of students to do independent research. Of 43 students and fellows with industry training grants or scholarships, 3 reported that they were expected to work on prescribed research problems, 3 must work for the supporting firms in the summer, and 9 must perform other activities for the

2. Michael Gluck et al., ‘University-Industry Relationships in the Life Sciences: Implications for Students and Post-Doctoral Fellows," *Research Policy, Vol.* 16, 1987, pp. 327-336. The authors warn that the data in their study come from the largest research universities in the country, and that risks could well be greater at the smaller institutions. They caution also against generalizing the results of this study to chemistry, engineering, or other fields with large industrial involvements, since their resources and research opportunities may differ substantially.

3. David Blumenthal et al., "Industry Support of University Research in Biotechnology: An Industry Perspective," Science, vol. 231, June 13, 1986, pp. 1361-1366.

firms' benefit. (It is not clear how much Federal support — particularly training grants — is given with similar strings attached, but Federal basic research funding generally does not restrict recipients' research topics.) Of the six universities involved in the student and faculty survey, two (Harvard and Massachusetts Institute of Technology) forbid firms from requiring trainees to perform such services.[4]

Some have expressed the concern that faculty may be distracted by their industry work from normal academic activities, and that students' socialization could thereby suffer. The process of socialization is at the heart of graduate education. The traditions and values of science are transmitted — largely by the faculty advisor's example — along with its methods. However, surveyed professors receiving research support from industry report significantly more university and professional activities than their colleagues without such support. They also report spending more time with students. Even faculty members holding equity in biotechnology companies show no neglect of their academic duties. (These results probably reflect the fact that companies form relationships with the more productive faculty members.)

Another aspect of socialization is the kind of career expectations transmitted. Here the survey finds no correlation with industry support; students and fellows with such support are no more or less likely than others to desire academic careers, for example.

Finally, for a very small percentage of students, who are supported by companies in which their faculty advisors own stock, there is the risk of conflict of interest; the advisor might direct students' research for the benefit of the company rather than that of the students.

The data suggest some changes associated with industry support. In a few cases industrial training grants and scholarships may be associated with increased trade secrecy, delayed publication, and inhibited scholarly discussion; data, however are only suggestive, not conclusive, on this point. The survey also indicates that trainees with industrial support publish significantly less than others; the evidence shows, however, that this pattern reflects individual predilections rather than effects of industry funding. (Faculty with industry research support, for example, publish more than their peers without such support.)

4. Gluck, op. cit., footnote 1.

These risks of industry funding are tempered by several conditions: 1) they are infrequent, 2) industry funds are outweighed overwhelmingly in university training efforts by Federal funds, and 3) they are subject to safeguards by university policies, which may provide guidelines for the industry involvement with students and fellows. Many institutions have already adopted guidelines promoting open communication of research, for example, and some have limited the conditions that may be attached to industry support.

It is important to recognize that academic research agendas and students' research and career interests are steered by many external factors, as well as their own predilections. The interests of faculty advisers, Federal funding availability, and the opportunities and limitations offered by available equipment and facilities all guide students. The as-yet unresolved fear is that industry may guide academic research in the United States more strongly and disruptively than other influences.

Box 3-I. — Preserving Young Science and Engineering Talent in Universities: Two European Programs

In western Europe, as in the United States, the problem of recruiting and retaining new research talent in universities has become a matter of concern. Stagnant demand for university faculty and high industrial salaries have drawn many bright young researchers away from universities. Several countries established programs to counter this trend.[1] The following examples are cited as innovations that could be adapted to the U.S. system of higher education and employment of scientists and engineers.

Federal Republic of Germany: Heisenberg Fellowships and the Fiebinger Plan

In West Germany, heavy faculty recruitments in the 1970s, in response to that decade's rising enrollments, left universities with little demand for additional faculty; budget cuts in the early-1980s further depressed demand. At the same time, growing enrollments produced many talented young researchers, some of whom have pursued the *Habilitation,* a postdoctoral degree considered a necessary qualification for appointment to a full chairholder post in a German university. To retain this pool of specialized talent in universities, where they may be ready to assume professorial positions when the 1990s bring retirements of many current faculty members, the government in 1978 established the Heisenberg Fellowships.

The holder of the *Habilitation* is considered to be prepared solely for the academic labor market, with a research training too inflexible for industrial research positions. In addition, the average recipient of this degree is over 38 years old, too old for entry into industry. Surveys show that only about 20 percent of the recently qualified *Habilitierten* have obtained the tenured professorships traditionally associated with the degree.

The Heisenberg program, run jointly by federal and provincial authorities, provides Habilitierten and others holding specialized academic degrees with university research

1. Based on a review of European programs by Guy Neave, "Science and Engineering Work Force Policies: Western Europe," OTA contractor report, 1987.

positions for up to 6 years. The program thus retains these highly-trained and talented people within the orbit of the university, holding them in reserve.

The Heisenberg Fellowships were considered a temporary measure, to bridge a short-term slump in academic demand. By 1983, however, it had become obvious that most of the first group of recipients would not find academic positions before their fellowships expired and that the faculty job market was unlikely to improve substantially before the 1990s.

The Federal Government responded by mandating artificial improvements in the job market. Under the Fiebinger Plan (named after the university president who proposed it), all 11 provincial governments are called on to increase the number of academic posts by 1 percent each year from 1985 to 1990. This measure will provide 200 additional jobs annually (at a cost of DM200,000 per job). The jobs in each province will be distributed by field according to assessments of needs for scientific and engineering research.

The Fiebinger Plan is large enough to maintain only one-fifth of new *Habilitierten* in universities. With faculty retirements not expected to turn upward until the 1990s, young researchers may still feel insecure about their futures. Some provinces, with this fact in mind, have encouraged early retirement of full professors, so that they may be replaced by younger staff (who, besides being young and creative, are at the bottom of the salary scale).

The United Kingdom: "New Blood"

Like the Federal Republic of Germany, the United Kingdom cut university budgets in the early-1980s. As in Germany, this step reduced opportunities to hire younger faculty; about 3,500 posts were abolished. Without new faculty, it was feared, British universities would fail to establish research programs in emerging fields — especially those considered important to the nation’s high-technology future.

In response, the University Grants Committee in 1982 established a “New Blood” program to bring bright young researchers onto university staffs. A secondary aim was to shift the distribution of academic posts away from the humanities and toward the natural and applied sciences considered critical to the nation’s scientific and economic future.

The program bears certain similarities to the German Fiebinger Plan. It funded academic research posts at universities, emphasizing new research lines of high promise, such as engineering, physics, the biological sciences, and information technology. University proposals for particular appointments were evaluated according to their potential impacts on the universities' research programs, and on the age distribution of academic staffs. The program was limited to researchers under the age of 35.

In the 3 academic years beginning with 1983-84, the program approved 792 posts at a total cost of about 22 million pounds. The average grant was £22,000 in the natural sciences, medicine, and technology, and f 16,000 in the humanities. Physics accounted for 25 percent of the posts established, engineering 18 percent, medicine 16 percent, the biological sciences 11 percent, the social sciences 9 percent, the humanities 8 percent, mathematics 8 percent, agriculture and veterinary studies 3 percent, and education 1 percent. Funding covers not only salaries, but also research expenses. Universities assume responsibility for financing after the initial grants are made.