Chapter 5
Academic Research and Development: Infrastructure and Performance

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HIGHLIGHTS

FINANCIAL INFRASTRUCTURE

- **The 1980s and the first half of the 1990s showed a continuing trend—observed over the past several decades—toward an increasing role for academic performers in total U.S. research and development (R&D).** From 1980 to 1995, academic performance rose from just above $6 billion to an estimated $21.6 billion (in current dollars), increasing from a 9.8-percent share to a 12.6-percent share of total U.S. R&D performance. The academic sector continues to be the largest performer of basic research in the United States.

- **During the 1984–94 period, average annual growth was much stronger for the academic sector than for any other R&D-performing sector.** The estimated average annual growth was 5.8 percent, compared with about 2.8 percent for federally funded research and development centers (FFRDCs) and other nonprofit laboratories; 1.4 percent for industrial laboratories; and 0.7 percent for Federal laboratories. The academic sector is the only one for which real growth is estimated between 1994 and 1995.

- **The Federal Government continues to provide the majority of funds for academic R&D.** In 1995, it provided an estimated 60.2 percent of the funding for R&D performed in academic institutions; this fell from 67.6 percent in 1980. In the 1991–95 period, and for the first time since 1978–80, Federal support grew faster than nonfederal support for 2 or more consecutive years.

- **Federal obligations for academic R&D are concentrated in three agencies: the National Institutes of Health (53 percent), the National Science Foundation (15 percent), and the Department of Defense (12 percent).**

- **The number of universities and colleges receiving Federal R&D support increased significantly during the past decade.** In 1993, 875 academic institutions received R&D support from the Federal Government, compared with 621 in 1981.

- **After the Federal Government, the academic institutions performing the R&D provided the second largest share of academic R&D support.** From 1980 to 1995, the institutional share grew from 13.8 percent to an estimated 18.1 percent of academic R&D expenditures.

- **Industrial R&D support to academic institutions has grown more rapidly than support from other sources since 1980.** In constant dollars, industry-financed academic R&D increased by an estimated 250 percent from 1980 to 1995. Industry's share grew from 3.9 percent to an estimated 6.9 percent during this period.

PHYSICAL INFRASTRUCTURE

- **Total academic science and engineering (S&E) research space increased by almost 14 percent between 1988 and 1994, from about 112 million to 127 million net assignable square feet.** When completed, construction projects initiated between 1986 and 1993 are expected to produce 43 million square feet of new research space and 43 million square feet of renovated research space.

- **Only modest changes in the condition of academic S&E research facility space occurred between 1988 and 1994.** The percentage of space available for use in the most scientifically sophisticated research increased (from 24 to 26 percent); the percentage effective for most uses, except the most scientifically sophisticated, declined (from 37 to 33 percent), the percentage of space needing limited repair/renovation remained about the same (23 percent), and the percentage requiring major repair/renovation or replacement increased (from 16 to 17 percent).

- **Expenditures for academic R&D instrumentation in U.S. research universities began declining recently.** It followed a pattern of large increases in investment throughout most of the 1980s. Constant dollar expenditures for academic research instrumentation averaged 8.5 percent annual growth between 1983 and 1989. This trend later reversed, and the level of support averaged a 7 percent annual decline between 1989 and 1993. Annual research equipment expenditures, as a percentage of total R&D expenditures, declined from 7.2 percent in 1986 to 5.2 percent in 1993.

- **Over 96 percent of S&E Ph.D. faculty with research as their primary activity had access to a personal computer, and 87 percent rated their personal computers as "good" or "very good."** About 71 percent also had access to both centralized computer facilities and networks with other institutions that were rated as "good" or "very good."

HUMAN INFRASTRUCTURE

- **Full-time employment of doctoral scientists and engineers in traditional faculty ranks—full, associate, and assistant professor, plus instructor—was essentially static since the late 1980s and stood at 172,000 in 1993.** Growth in other positions slowed markedly after 1989, following annual increases of about 3 percent during the 1980s. Total employment in 1993 stood at 213,000.

- **Most faculty with heavy time investment in research had teaching responsibilities.** About one-third of them taught undergraduates in the fall of 1992; the others taught graduate courses. The institutional setting—research universities versus other types of academic institution—had little effect on these patterns.

- **The number of doctoral scientists and engineers with research as their primary or secondary work responsibility rose rapidly through the 1980s, but in 1993 their number stood at about 150,000—roughly the same level as in 1989.**

- **The aging of the academic research workforce, observed since the early 1970s, has ceased.** The proportion of researchers who had obtained their doctorate within 3 years of the survey declined steadily from 24 percent in 1973 to 14 percent in 1989, where it has stabilized. Trends for total employment and for those in traditional faculty positions are similar.

- **The gradual replacement hiring suggested by these data for the 1990s contrasts with the preceding decade, when the number of full-time faculty positions increased at a fairly steady rate and when smaller numbers of doctorates were awarded than in recent years.**

- **About 46,500 female doctoral scientists and engineers worked in academia in 1993. Female employment figures grew steadily in the 1970s and more than doubled from 1981 to 1993.** The number of females active in academic R&D tripled from 1979 to 1993, when it stood at 30,500 (or about 20 percent of all academic researchers).

- **Although the overall number of black, Hispanic, and Native American researchers increased, it remained low.** In 1993, their combined academic employment—10,800—was about 5 percent of the total, the same as their fraction of academic researchers. The slowly increasing share of underrepresented minorities in academic employment roughly reflects their Ph.D. conferral rates.

- **About 21,000 Asians held academic positions in 1993. They constituted 10 percent of academic employment—up from 8 percent in 1979—and 12 percent of all academic researchers in 1993.** Their share of academic researchers consistently has been about 2 percentage points above their employment share.

- **In 1993, about 16,000 nondoctoral scientists and engineers reported that research was their primary or secondary work activity.** Two-thirds of them held professional degrees, often combined with a master's degree. The majority worked in the life sciences or in engineering.

- **In 1993, about 27 percent (or 89,729) of all full-time graduate students in science and engineering received primary support from research assistantships, roughly half of which were federally funded.**

- **Thirty-eight percent of academic doctoral scientists and engineers reported receiving support from the Federal Government in the spring of 1993.** Life sciences (53 percent) and environmental sciences (52 percent) had the highest support rates; mathematics (21 percent) and the social sciences (15 percent) had the lowest.

- **More researchers in 1993 than a decade earlier reported relying on multiple Federal agencies for support.** Twenty-five percent of those with Federal Government support in 1993 reported receiving funds from more than one agency.

ARTICLE OUTPUTS

- **The United States contributed about one-third of the world's 414,000 articles appearing in a set of nearly 4,000 international, peer-reviewed natural science and engineering journals; about 70 percent of the U.S. articles had academic authors.** Western Europe's combined share roughly equaled that of the United States. Contributions from Asian nations, reflecting strong growth in Japan, China, and the rapidly industrializing nations, rose to 15 percent of the world's total.

- **National science portfolios differ among countries.** Compared with the world average, the United States places relatively more emphasis on clinical medicine, biomedical research, and earth and space sciences and relatively less emphasis on chemistry and physics. Major European nations show relatively more emphasis on chemistry and physics and less on the medical and life sciences. A similar but more intensified pattern is present in Asian nations, along with a strong emphasis on engineering and technology.

- **A pronounced worldwide tendency exists toward greater collaboration in scientific research.** This has been accompanied by a marked increase in collaboration across national boundaries. In 1993, roughly half of all journal articles worldwide had multiple authors, and about one-quarter of these involved coauthorship across national boundaries.

- **International scientific collaboration centers, to a remarkable degree, on the United States.** For example, roughly 20 to 25 percent of internationally coauthored European papers involved U.S. authors. In Japan, India, and China, the proportion of papers involving U.S. authors ranged between 30 and 45 percent; for the rapidly industrializing nations of Asia, it approached half. In contrast, no single country's authors exceeded 12 percent of internationally coauthored U.S. papers.

- **Scientific and engineering research in the United States has increasingly involved investigators from different employment sectors.** Just under one quarter (23 percent) of all academic papers in 1993 involved authors from one or more other sectors: 8 percent each from the Federal Government and nonprofit institutions, 5 percent from industry (double the 1981 percentage), 3 percent from FFRDCs, and 2 percent from other sectors, including state government.

- **Citations of scientific and technical literature in patent awards increased to almost 50,000 in 1993–94 (a threefold rise from 1987–88).** Roughly half of the references were to papers from academic institutions, and one quarter were to industry papers. About two-thirds were to articles on biomedical research and clinical medicine.

- **The frequency of citations served as a rough indicator of the perceived usefulness of a country's articles to scientists elsewhere.** The United States' share of citations exceeds its share of publications, and in virtually all other countries' journals, U.S. articles are cited more heavily than the domestic literature. It appears fair to conclude that U.S. scientific and technical articles are found quite useful by scientists worldwide.

Academic Patenting

- **In 1994, patents awarded to U.S. academic institutions continued their rapid increase, with 1,761 patents awarded, compared with only 434 a decade earlier.** The academic sector's share of all U.S. patent awards rose to 3 percent from less than half that in 1991 and from 1 percent in 1980.

- **In 1994, only three patent-use classes, all related to biomedical activity, accounted for 25 percent of all academic patents, compared to 7 percent in 1980.**

- **More and more academic institutions are receiving patents, and the 100 largest research universities account for a large and growing share.** These universities, which accounted for roughly 80 percent of total academic R&D expenditures, received about 90 percent of all academic patents.

- **Income from royalties and licensing agreements, while still modest compared with R&D expenditures, increased steeply in recent years and was approximately $242 million in 1993.**

Introduction

Chapter Background

Academic research and development (R&D) and science and engineering (S&E) educational activities are a significant part of the national R&D enterprise. The academic sector now accounts for an estimated 12.6 percent of national R&D expenditures. It is also the largest performer of U.S. basic research, accounting for about 49 percent of national basic research expenditures. Forty-six percent of doctoral scientists and engineers are employed by the Nation's universities and colleges, and they produce 71 percent of the United States'—and 24 percent of the world's—scientific and technical articles published in major peer-reviewed journals. This chapter addresses the following four principal aspects of academic R&D:

- *Financial infrastructure*—academic R&D in a national context; sources of funding; allocation of funds across both institutions and S&E fields; the Federal Government's funding role and objectives; the importance of individual Federal agencies across S&E fields; the spreading institutional base of federally funded academic R&D; and research on university/industry R&D linkages;
- *Physical infrastructure*—the need for, and the funding and adequacy of, S&E research facilities and research instrumentation;
- *Human infrastructure*—characteristics and activities of academic scientists and engineers, with emphasis on doctoral personnel and full-time faculty; the interplay of teaching and research activities; the involvement of graduate students and other nondoctoral personnel in academic R&D; and changes in the age structure of the academic workforce; and
- *Research outputs*—the publication of papers and articles in a core set of international scientific and technical journals; cross-sectoral and international coauthorship patterns; cross-sectoral and international citations of this literature; citations in U.S. patents of U.S. articles; and patents awarded to academic institutions.

Chapter Organization

The chapter opens with a discussion of trends in financial resources provided for academic R&D, including allocations across both academic institutions and S&E fields. For over half a century, the primary source of support for academic R&D has been the Federal Government. Its role and objectives and the importance of selected agencies for individual S&E fields are explored in greater detail in section one. Recent developments related to indirect cost and data on changes in the number of academic institutions receiving Federal R&D support are also presented. Because of an increasing interest in partnerships that promote investments in academic R&D, this section also includes a discussion of selected research on the factors affecting university/industry linkages.

The second section of the chapter examines the status of two key elements of university research infrastructure—facilities and instrumentation. Topics explored include funding, adequacy, and need. A new feature of this section is a special focus on the availability of data on the use of computers in academia.

The third section discusses trends in the employment and characteristics of academic S&E doctorate holders. The central focus is on academic researchers: their number and characteristics, including field of degree, age, sex, and race/ethnicity, and the extent of Federal support. Trends are examined in the reported primary work responsibility for research or teaching of S&E doctorates in regular faculty positions. The interplay of teaching and research responsibilities is discussed and examined separately for major research universities and other institutions. This section also presents data on the participation of graduate research assistants and other nondoctoral personnel in academic R&D and concludes with a discussion of the faculty age structure.

The chapter's final section covers two types of academic R&D output: the publication of articles in the natural sciences and engineering in a set of about 4,000 international peer-reviewed journals and patents issued to U.S. universities. (Educated and trained personnel, as a major output of academic R&D, is discussed in Chapter 2, Higher Education in Science and Engineering.) The discussion on article outputs places the United States in the context of other countries contributing to the world literature. It has four broad foci:

- The sheer output volume of research—article counts;
- Collaboration in the conduct of research—joint authorship;
- Use in subsequent scientific activity—citation patterns; and
- Use beyond science—references to citations of the literature in patent applications.

Financial Infrastructure for Academic Research and Development

This section focuses on the levels and sources of support for R&D activities at U.S. universities and colleges.[1]

[1]Data in this section come from several different National Science Foundation (NSF) surveys, which do not always use comparable definitions or methodologies. NSF's three main surveys involving academic R&D are (1) the Federal Funds for Research and Development Survey; (2) the Federal Support to Universities, Colleges, and Selected Nonprofit Institutions Survey; and (3) the Scientific and Engineering Expenditures at Universities and Colleges Survey. The results from the third survey are based on data obtained directly from universities

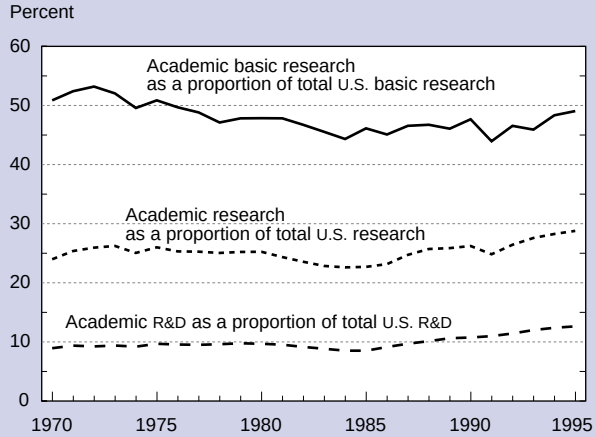
Beginning with an examination of the role of academic R&D in the context of the national R&D system, it covers R&D funding patterns in terms of funding sources and their distribution among academic institutions and across S&E fields. The roles of the Federal Government, industry, and academic institutions in supporting R&D at universities and colleges are explored in some detail. Specifically, data are presented on the increase in the share of academic R&D support provided by the institutions themselves, the expansion in the number of academic institutions receiving Federal R&D support, and the factors affecting industry's support of academic R&D.

Academic Research and Development in a National Context

In 1995, an estimated $21.6 billion was spent for R&D at U.S. academic institutions.[2,3] This level of expenditure represents a continuing trend, observed over the past several decades, of an increasing role for academic performers in total U.S. R&D. Academic R&D in 1995 made up an estimated 12.6 percent of total R&D, compared with about 11 percent in 1990, 10 percent in 1980, and about 9 percent in 1970. During the 1970–95 period, the proportion of total U.S. research[4] expenditures in academic institutions was around 25 to 29 percent, while the proportion of total basic research expenditures fluctuated between 40 and 50 percent, making the academic sector the largest performer of basic research. (See figure 5-1.)

In constant 1987 dollars, average annual R&D growth between 1984 and 1994 was much stronger for the academic sector than for any other R&D-performing sector—an estimated growth of 5.8 percent, compared with about 2.8 percent for federally funded research and development centers (FFRDCs) and other nonprofit laboratories, 1.4 percent for industrial laboratories, and 0.7 percent for Federal laboratories. Since 1990, however, academic R&D has grown at an estimated average annual rate of only 2.8 percent, which is still higher than for any of the other three main R&D performing sectors. From 1994 to 1995 the academic sector is the only one for which positive growth is estimated, albeit at only 0.4 percent. As a proportion of the gross domestic product, academic R&D rose significantly from 0.23 to 0.31 percent between 1980 and 1994.

Figure 5-1.
Academic R&D, research, and basic research as a proportion of U.S. totals



NOTES: Academic research includes basic research and applied research. Data for 1994 and 1995 are estimates.

See appendix tables 4-4, 4-5, and 4-6.

Science & Engineering Indicators – 1996

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development work.[5] Of 1995 academic R&D expenditures, an estimated 67 percent was for basic research, 25 percent for applied research, and 8 percent for development. (See appendix table 5-1 and figure 5-2.)

Sources of Academic Research and Development Funds

The Federal Government continues to provide the majority of funds for academic R&D. (For a brief discussion of the Administration's goals for fundamental research, see *Federal Academic Research Funding and National Priorities*.) In 1995, the Federal Government provided an estimated 60.2 percent of the funding for R&D performed in academic institutions. This was down from 67.6 percent in 1980, and 70.5 percent in 1970. Although participation by other sectors had been growing faster than that of the Federal Government up through the early 1990s, the reversal of this trend, beginning in 1992, ended the long-term pattern of declining share of Federal support for academic R&D. (See figure 5-3.) For the first time since the 1978–80 period, the 1991–95 period showed faster growth for Federal support than for nonfederal support for 2 or more consecutive years, even though growth in all sources has been slowing down in recent years.

and colleges; the first two surveys collect data from Federal agencies. For descriptions of the methodologies of these and other selected NSF surveys, see SRS (1995f, h). Federally funded research and development centers associated with universities are tallied separately and are examined in greater detail in Chapter 4, Research and Development: Financial Resources and Institutional Linkages.

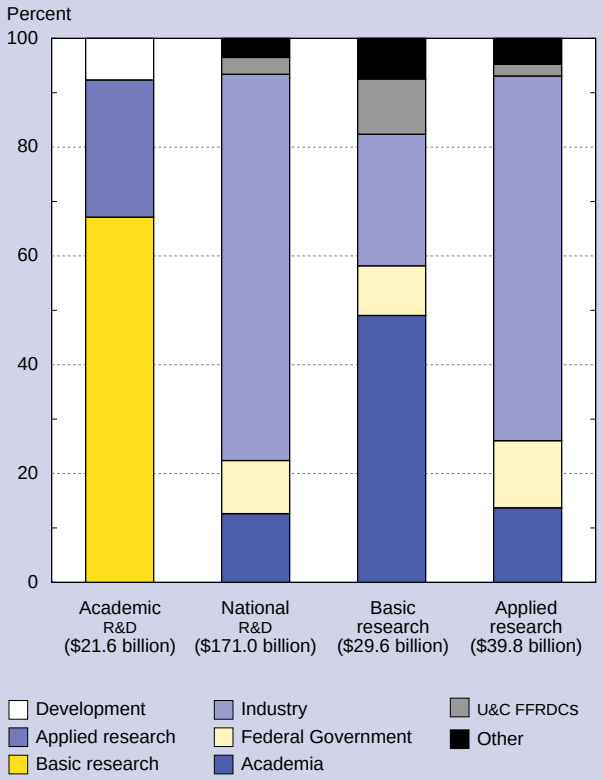
[2]This discussion is based on data in SRS (1995g) and unpublished tabulations. For more information on national R&D expenditures, see Chapter 4, Research and Development: Financial Resources and Institutional Linkages.

[3]Academic insitutions generally comprise institutions of higher education that grant doctorates in science or engineering and/or spend at least $50,000 for separately budgeted R&D.

[4]This research includes basic research and applied research. For definitions of basic research, applied research, and development, see Chapter 4, Research and Development: Financial Resources and Institutional Linkages.

[5]Notwithstanding this delineation, "R&D"—rather than just "research"—is used throughout most of this discussion since almost all of the data collected on academic R&D do not differentiate between "R" and "D."

Figure 5-2.
National and academic R&D expenditures, by character of work and performer: 1995



U&C = university and college
FFRDC = federally funded research and development center

NOTE: Data are estimates.

See appendix tables 4-4, 4-5, 4-6, and 5-1.

Science & Engineering Indicators – 1996

The following is a discussion of the contributions from other sectors to academic R&D.[6]

- *Institutional funds*—These are separately budgeted funds spent on R&D by an academic institution from unrestricted sources, unreimbursed indirect costs associated with externally funded R&D projects, and mandatory and voluntary cost sharing on work funded by Federal and other grants. (For recent changes in reimbursement policies for indirect costs for federally funded R&D, see *Recent Developments on the Indirect Cost Front*. For additional information on institutional funds, see *The Composition of Institutional Academic R&D Funds*.) These constitute the second largest source of academic R&D funds. From 1980 to 1991, the institutional share grew from 13.8 to 19.1 percent of all academic R&D expenditures. After this extended period of growth, the share declined to 18.8 percent in 1992 and 17.8 percent in 1993. Since 1993, a slight upturn to an estimated 18.1 percent occurred in the share. The major sources of institutional R&D funds are (1) general-purpose state or local government appropriations, particularly for public institutions; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) gifts that are not restricted by the donor to research. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues.[7] (See Income from Patenting and Licensing Arrangements for a discussion of patent and licensing income.)[8]

- *State and local government funds*—The share of academic R&D funding from state and local governments fluctuated slightly between 7.8 and 8.4 percent between 1980 and 1991 before it declined steadily to an estimated 7.4 percent in 1995. This share, however, reflects only funds targeted specifically for academic R&D activities and does not include general-purpose state or local government appropriations used for separately budgeted research or to cover unreimbursed indirect costs. Consequently, the actual contribution of state and local governments to academic R&D is understated, particularly for public institutions.

- *Other sources of funds*—These include grants from nonprofit organizations; voluntary health agencies; and gifts from private individuals that are restricted by the donor to research; as well as all other sources not elsewhere classified as restricted to research purposes. Since 1986, this source of academic R&D support has increased its share from 6.7 to an estimated 7.4 percent.

- *Industry funds*—During the past 2 decades, funds from the industrial sector for academic R&D grew faster than funds from any other source. (See *Selected Research on University/Industry Research and Development Linkages* for a discussion of some of the factors affecting industrial support for academic R&D.) Industry increased its share of support from 2.6 percent in 1970 and 3.9 percent in 1980 to an estimated

[6]The academic R&D funding reported includes only separately budgeted R&D and institutions' estimates of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing. It does not include departmental research and thus will exclude funds, particularly for faculty salaries, in cases where research activities are not separately budgeted.

[7]A survey conducted by the Association of American Medical Colleges estimated, based on responses from just under half of all academic medical centers, that revenues from faculty practice contribute approximately $800 million to academic research. See Marshall (1995) and Neville (1995).

[8]Some of the rapid growth in institutional R&D funds may be due to accounting changes, including both a shift from departmental research to separately budgeted research and increased institutional skill in calculating unreimbursed indirect costs, including mandatory and voluntary cost sharing. Available data suggest, however, that it is unlikely that this accounts for the bulk of the increase. Growth in institutional R&D funds has been roughly in line with growth in academic institutions' total operating expenditures over the past 2 decades. Growth also has been steady over the entire period, without the sudden shifts one would expect if better or significantly different reporting were to occur simultaneously in a large number of institutions.

Federal Academic Research Funding and National Priorities

"Science, both endless frontier and endless resource, is a critical investment in the national interest. Science and technology are tightly coupled, for they both drive and benefit one another. To address the nation's science investment strategy, we must reexamine every element of the enterprise: the research portfolio; the infrastructure needed for world-class research by world-class researchers; and the education of our people in science and mathematics. Each element must be strong, requiring that optimization be done within limited resources. It is essential that we adhere to a long-range and diversified investment strategy: nurture broadly based fundamental research for the decades ahead, conduct research aimed at today's strategic areas, and undertake vigorous development activities that spring from our accumulated science and engineering resource base."

The above quotation is from *Science in the National Interest*, President Clinton and Vice President Gore's August 1994 statement on the Administration's long-term goals and objectives for the U.S. science and engineering fundamental research and education enterprise. The Administration's over-arching goal for fundamental research is stated as "world leadership in basic science, mathematics, and engineering."

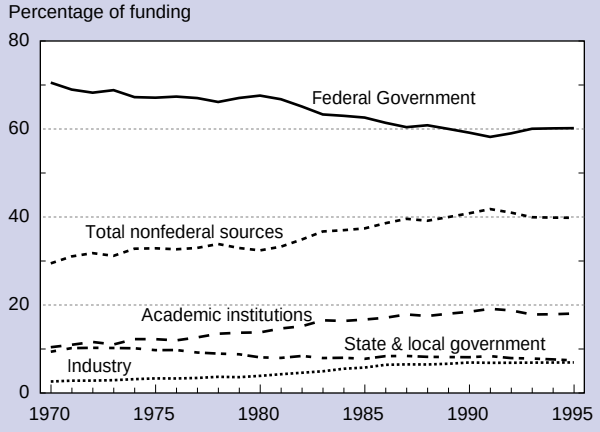
The statement acknowledges the important role U.S. academic institutions play in the science and engineering enterprise. It states that "[a] significant fraction of research, particularly fundamental research, is performed at academic institutions. This has multiple benefits. Research and education are linked in an extremely productive way. The intellectual freedom afforded academic researchers and the constant renewal brought by successive generations of inquisitive young minds stimulate the research enterprise. A broad range of disciplines are represented in our research universities, providing opportunity for cross disciplinary stimulation."

The document notes that, in order to sustain its current leadership position, the United States "must improve the conditions, capabilities, and opportunities for well-trained scientists and engineers to pursue innovative research; to educate the next generation; and to apply science in areas of importance to the health, prosperity, and security of the country." To meet these ends, the Administration sets the following goals for its stewardship of science in the national interest:

- Maintain leadership across the frontiers of scientific knowledge;
- Enhance connections between fundamental research and national goals;
- Stimulate partnerships that promote investments in fundamental science and engineering and the effective use of physical, human, and financial resources;
- Produce the finest scientists and engineers for the 21st century; and
- Raise scientific and technological literacy of all Americans.

Each of these goals, and the policies enacted to fulfill them, will have important implications for the U.S. academic R&D infrastructure.

Figure 5-3.
Sources of academic R&D funding, by sector



NOTE: Data for 1994 and 1995 are estimates.
See appendix table 5-2.

Science & Engineering Indicators – 1996

6.9 percent in 1995. Industry's contribution to academia represented about 1.5 percent of all industry-funded R&D in 1995, compared with 0.8 percent in 1980 and 0.6 percent in 1970.

Patterns of sectoral funding of academic R&D vary depending on the type of academic institution involved. That is, private and public universities differ in their major sources of R&D support. (See appendix table 5-3.) For public academic institutions, just under 11 percent of R&D funding in 1993 came from state and local funds, about 22 percent from institutional funds, and about 54 percent from the Federal Government. Private academic institutions received about 2 percent of funds from state and local government, 9 percent from institutional sources, and 73 percent from the Federal Government. Both public and private institutions received approximately 7 percent of their respective R&D support from industry in 1993. Over the past 2 decades, the Federal share of support declined and the industry and institutional shares increased for both public and private institutions.

Recent Developments on the Indirect Cost Front

The process of indirect cost reimbursement for R&D at academic institutions underwent considerable change during the 1990s with a number of attempts to revise Circular A-21, the Office of Management and Budget (OMB) document governing indirect cost reimbursement policies, documentation, and accounting practices. In October 1991, OMB issued rules revising Circular A-21 to limit the administrative costs portion of indirect costs to 26 percent of modified direct costs. Changes were also made to exclude certain items from indirect cost rate calculations and to remove ambiguities in the interpretation of Circular A-21 to prevent the shifting of capped indirect costs to direct costs. The revision now also requires universities to provide periodic assurances that reimbursement for use allowances and for buildings and equipment depreciation will be used exclusively for facilities or equipment expenditures. A March 1995 General Accounting Office (GAO) study found that the 26-percent cap reduced government spending for indirect administrative indirect costs in 1993 by approximately $104 million.

In 1992, OMB and the Office of Science and Technology Policy (OSTP) created a task force to examine issues related to indirect cost reimbursement to universities and colleges. This activity culminated in proposed changes to Circular A-21 that the Clinton Administration adopted and that OMB published in July 1993 in the *Federal Register*. The seven categories or "pools" of indirect costs used to determine the overhead rate have been aggregated into two broad categories: administrative and facilities. Any costs not identified as facilities are to be shifted to the administrative category and be subject to the 26-percent cap. These changes also emphasize that salaries of administrative and clerical staff should normally be treated as indirect costs (although direct charging of these costs may be appropriate in certain circumstances where the individuals involved can be specifically identified with the project or activity). Tuition remission, as a fringe benefit, also has been targeted for phase-out, with the specification that tuition for graduate students working on federally funded research be treated as a direct cost. An OSTP-led task force is currently reviewing this change because there have been concerns expressed with its possible adverse effect on the support of graduate students.

In 1994, President Clinton's FY95 budget proposed a temporary "pause" in the indirect cost rate so that an institution (receiving more than $10 million in Federal R&D funds) could recoup no more than the amount of indirect costs received in FY94, even if the amount of federally funded research it might conduct increases. This "pause" and several additional proposals to limit indirect costs introduced to Congress during this period were not enacted.

In February 1995, the Clinton Administration proposed further revisions to A-21 designed to achieve greater uniformity in university methods and procedures for calculating indirect costs. These proposed revisions include simplifying terminology to enable the public to better understand the components of research costs; clarifying and making policies for university changes from use allowances to depreciation consistent across Federal agencies; eliminating special studies to reduce variations in the utility, library, and student services portions of overhead rates; fixing the recovery rate for the life of an award at the rate in effect at its inception; eliminating the allowability of dependent tuition benefits; establishing criteria for the appropriate treatment of interest costs; assigning cost negotiation to the Office of Naval Research and the U.S. Department of Health and Human Services, based upon predominance of Federal funding; and assigning responsibility for coordinating policy development for sponsored agreements to an interagency working group. There are also a number of other areas undergoing further study.

Distribution of Research and Development Funds Across Academic Institutions[9]

Most academic R&D is, and has been, concentrated in relatively few of the 3,600 higher education institutions in the United States.[10] In fact, when all such institutions are ranked by their 1993 R&D expenditures, the top 200 institutions account for 95.6 percent of R&D expenditures. In 1993,

- The top 10 institutions spent 17 percent of total academic R&D funds ($3.4 billion);
- The top 20 institutions spent 31 percent ($6.0 billion);
- The top 50 spent 57 percent ($11.0 billion); and
- The top 100 spent 80 percent ($15.6 billion).[11]

[9]For a comprehensive discussion on this subject see a recent paper by Geiger and Feller (1995).

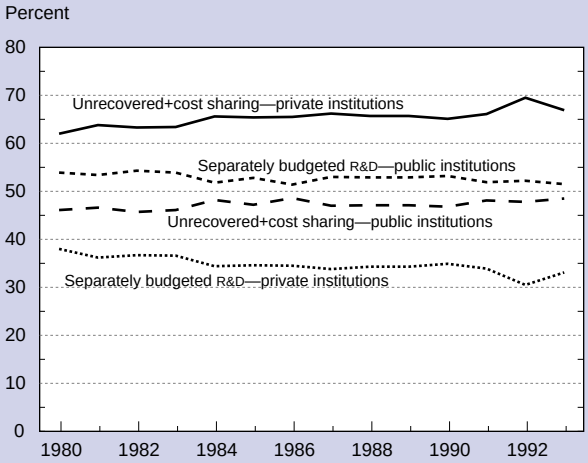
[10]The Carnegie Foundation for the Advancement of Teaching classified 3,600 degree-granting institutions as higher education institutions in 1987. (See Chapter 2, Higher Education in Science and Engineering, for a brief description of the Carnegie categories.) These higher education institutions include 4-year colleges and universities, 2-year community and junior colleges, and specialized schools such as medical and law schools. Not included are more than 7,000 other postsecondary institutions (secretarial schools, auto repair schools, etc.).

[11]These percentages exclude the Applied Physics Laboratory (APL) at the Johns Hopkins University. With an estimated $212 million in FY83 and $447 million in FY93, APL performs about 60 to 70 percent of the university's R&D. Although not officially classified as an FFRDC, APL essentially functions as one. Its exclusion therefore provides a better measure of the distribution of academic R&D dollars and the ranking of individual institutions.

The Composition of Institutional Academic Research and Development Funds

Institutional academic R&D funds grew faster than funds from any other source, except industry, during the past 2 decades. (See appendix table 5-2.) In 1995, academic institutions are estimated to have committed a substantial amount of their own resources to R&D: roughly $3.9 billion or 18 percent of total academic R&D. Institutional support for academic R&D from public institutions was greater (at 22 percent) than from private institutions (at 9 percent). (See appendix table 5-3.) One possible reason for this difference is that public universities and colleges' own funds may include considerable state and local funds not specifically designated for R&D but used for that purpose by the institutions. Through all of the 1980s and early 1990s, institutional R&D funds were divided roughly equally between its two components: separately budgeted institutional R&D funds, and mandatory and voluntary cost sharing plus unreimbursed indirect costs associated with R&D projects financed by external organizations. Public and private institutions own funds differ not only in their importance to the institution, but also in their composition. In private institutions, 65 to 70 percent of their own funds is classified as unreimbursed indirect costs plus cost sharing, compared with 47 to 48 percent in public institutions. (See figure 5-4.)

Figure 5-4.
Components of "own" R&D expenditures for public and private academic institutions



SOURCES: Science Resources Studies Division (SRS), National Science Foundation, *Academic Science and Engineering R&D Expenditures: Fiscal year 1993, Detailed Statistical Tables,* NSF 95-332 (Arlington, VA: NSF, 1995); and SRS, special tabulations.

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This historic concentration of funds, however, diminished somewhat during the past decade. In 1983, the top 10 institutions received about 20 percent of the funds. The decline in this group's share of total academic R&D funds is nearly matched by the increase (from 17 to 20 percent) in the share of those institutions below the top 100. The institutions that ranked from 11 to 100 received almost the same share in 1993 (62.6 percent) as they did in 1983 (63.3 percent). (See appendix table 5-4.)

Academic Research and Development Expenditures by Field and Funding Source[12]

By far, the majority of academic R&D expenditures in 1993 went to the life sciences, which accounted for 54 percent of total academic R&D expenditures, 53 percent of Federal academic R&D expenditures, and 56 percent of nonfederal academic R&D expenditures. Within the life sciences, the subfield of medical sciences accounted for 27 percent of total academic R&D expenditures and the subfield of biological sciences accounted for 18 percent. The next largest block of total academic R&D expenditures (16 percent in 1993) was for engineering. (See appendix table 5-5. For detailed data on expenditures over time by S&E field and subfield, also see appendix table 5-6.) (For further information on the nature of engineering research being performed in U.S. universities, see *The Nature of Engineering Research at U.S. Universities.*)

Between 1983 and 1993, academic R&D expenditures for all fields combined grew at an average annual rate of 6.0 percent in constant 1987 dollars. (See figure 5-5 for constant dollar expenditures over the decade, by field.) Funding for the computer sciences grew fastest during the decade and increased at an average annual rate of 8.5 percent in constant dollars. However, R&D expenditures for the computer sciences in 1993 were only about 3 percent of total academic R&D. Funding for the engineering field grew second fastest during the decade and increased at an average annual rate of 7.1 percent. Within engineering, growth in funding was fastest for mechanical engineering (at 8.6 percent) and slowest for electrical engineering (at 6.5 percent). Academic R&D expenditures in the physical sciences grew the slowest, averaging 5.2 percent. Within the physical sciences, chemistry and physics grew the slowest (4.5 percent and 4.6 percent, respectively) and astronomy grew most rapidly (at 9.3 percent).

The distribution of Federal and nonfederal funding for academic R&D in 1993 varied by field and subfield. (See appendix table 5-5.) For example, the Federal Government supported 76 percent of academic R&D expenditures in the physics and atmospheric sciences subfields,

[12]The data in this section were drawn from the NSF's Scientific and Engineering Expenditures at Universities and Colleges Survey. For various methodological reasons, parallel data (by field) from the Foundation's Survey of Federal Obligations to Universities and Colleges do not necessarily match these numbers.

Selected Research on University/Industry Research and Development Linkages

A major development over the past 2 decades has been the growth in industrial support of academic R&D. As a result of this development, a number of important questions have arisen. To what extent have industrial innovations in various industries been based on academic R&D? What factors determine which universities will be supported by industrial firms to do R&D of various types? What characteristics of the universities and academic researchers seem to have contributed most to industrial innovation? Who has funded the research that has provided important contributions to industry? Over the past several years, Edwin Mansfield of the University of Pennsylvania has carried out a number of research projects directed at answering many of these and other related questions (Mansfield, 1995 a, b, c; Lee and Mansfield, 1995).

As part of this research, Mansfield indicated that industrial innovation in a number of industries has been based, to a substantial degree, on academic research. In the absence of academic research, many new products and processes could not have been developed at all or without substantial delay. Based on these results, rough and conservative estimates of the social rate of return from academic research exceeds 20 percent. In updating some of his earlier findings, Mansfield found a decrease in the mean time interval from approximately 7 years to 6 years between academic research results and the first commercial introduction of new products and processes.

Mansfield also examined how location and faculty quality affect the probability of a firm supporting R&D at a particular university. He found that, when the National Academy of Sciences (NAS) faculty quality rating is held constant, the mean proportion of R&D supported at a university within 100 miles of a firm is more than double that of a university located 100 to 1,000 miles away and generally more than triple that of a university more than 1,000 miles away. Geographic proximity, however, seems to play a smaller role for basic research than for applied R&D, while the effects of faculty quality are much smaller for applied R&D than for basic research. Distance is particularly important for universities with only adequate-to-good or marginal faculties. Their chance of support is quite low unless they are within 100 miles of the firm.

Mansfield also attempted to identify the characteristics of the universities and academic researchers that contributed most to industrial innovation and to determine who funded them. He selected a random sample of 70 major firms from a number of industries. Each firm was asked to cite about five academic researchers whose work in the 1970s and 1980s contributed most importantly to the firm's new products and processes in the 1980s. He found that, although in most industries the most frequently cited universities were world leaders in science and technology, about 40 percent of the citations went to universities with less than good-to-distinguished faculties in the relevant departments, according to NAS ratings. He also found that the bulk of the cited academic research occurred in departments closely related to the technology of the industry in question. Almost all of the cited researchers had some government support for their research, with the Federal Government providing about two-thirds of the funding. Over four-fifths of these researchers also received research support from industry. In most cases, the industry-funded work followed the government-funded work and was often directed at extending the latter. (See Cross-Sectoral Collaboration in the United States in this chapter; Industrial Science and Technology Linkages in Chapter 4, Research and Development: Financial Resources and Institutional Linkages; and Chapter 8, Economic and Social Significance of Scientific Research, for additional information.)

but only 29 percent of academic R&D in the agricultural and political sciences and public administration subfields.

It is noteworthy that the declining Federal share in the support of academic R&D is not limited to particular S&E disciplines. Rather, the federally financed fraction of support declined over the past 2 decades for each of the S&E fields except for computer sciences. (See appendix table 5-7.) The most dramatic decline occurred in the social sciences (from 57 percent in 1973 to 38 percent in 1993); the smallest decline was in the mathematical sciences (from 78 to 75 percent). In the computer sciences, Federal support was 70 percent in 1973 and 71 percent in 1993. The overall decline in Federal share also holds for all reported S&E subfields.

Support of Academic Research and Development by Federal Agencies

Federal obligations for academic R&D are concentrated in three agencies: NSF, the National Institutes of Health (NIH), and the Department of Defense (DOD). Together, these agencies are estimated to have provided approximately 80 percent of total Federal funds in 1995 for academic R&D: 53 percent from NIH; 15 percent from NSF; and 12 percent from DOD. (See appendix table 5-8.) If only academic research is considered, excluding development, agency shares are almost the same as for R&D. Since 25 to 30 percent of DOD's academic R&D obligations are directed toward development while almost all of NSF funds are for research, a slight shift occurs with the estimated NSF share increasing to 17

The Nature of Engineering Research at U.S. Universities

In January 1992, the Center for Technology Assessment and Policy at Washington University in St. Louis began a multiyear study of university-based engineering research. Led by Robert P. Morgan and supported by the National Science Foundation, the study tried to obtain a clearer picture of the nature of engineering research at U.S. universities, to analyze major trends and factors influencing university-based engineering research, and to examine how university-based engineering research serves society's educational needs. The survey research portion of the work was divided into two parts: a national survey of university-based engineering research units (conducted in the spring of 1993) and a national survey of engineering faculty (conducted in the fall of 1993) (Morgan et al., 1994a, b). The latter survey was based on a stratified probability sample drawn from the approximately 20,000 engineering faculty in the 200 universities that account for roughly all of U.S. academic engineering research expenditures. More than 1,700 usable responses (representing a 61-percent response rate) were received from individuals at 192 of these institutions. The following conclusions were drawn from these responses.

A shift away from the individual investigator model toward more applied research of a cross-disciplinary nature appears to be taking place. Despite this shift, traditional outputs such as papers for presentations, theses, and conference papers continued to be of much greater importance to faculty than commercial processes and products, patents, or invention disclosures. Faculty, however, considered the latter outputs somewhat more important now than when they began university-based engineering research.

Although industry has considerable involvement in university-based engineering research, close to 80 percent of faculty desired even greater industry involvement. About 79 percent of faculty reported support from industry while at their current university; some two-thirds reported an average of 5.8 years of experience in industry or government; and some 87 percent reported having been a consultant to industry or government while a faculty member.

Graduate students continue to play a central role in university-based engineering research, primarily serving as associate or independent researchers. However, student interaction with industrial and government researchers was not strongly indicated.

Engineering faculty involvement in research was roughly in balance with their involvement in teaching. For those currently involved in research, about 80 percent of the 1992–93 academic year was divided evenly between teaching and research; the rest was devoted mainly to administration.

The problems most frequently cited by engineering faculty were the excessive time required to obtain and sustain research support, the shortage of time to conduct research, and the instability and inconsistency of funding.

Data from both surveys are being analyzed further. The authors hope to combine these data with other analyses and provide a comprehensive picture of engineering research in U.S. universities.

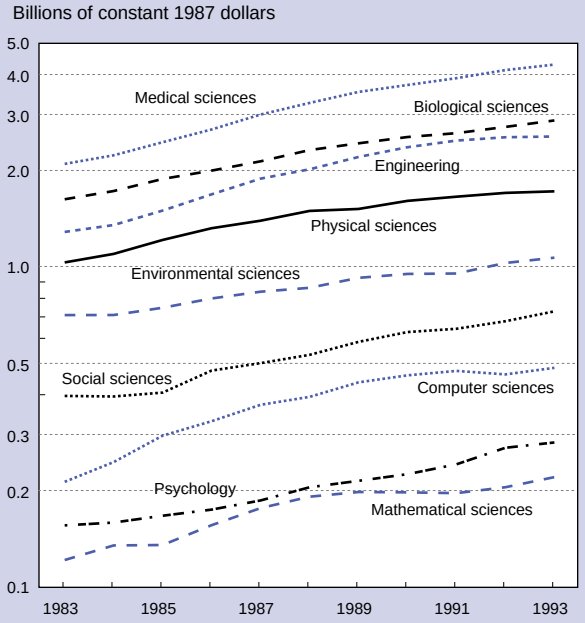
percent and the DOD share declining to 10 percent. (See appendix table 5-9.)

During the past 10 years, the National Aeronautics and Space Administration (NASA)—which is estimated to have provided about 6 percent of Federal support in 1995—had the highest estimated average annual growth in its funding of academic R&D: 8.5 percent per year (in constant 1987 dollars). The next highest growth rates were experienced by NIH (4.1 percent) and NSF (2.9 percent). Between 1994 and 1995, total Federal obligations for Federal R&D were estimated to have declined in constant dollars. Only NIH and NSF were expected to increase their academic R&D obligations in 1995.

Federal Academic Research Funding by Science and Engineering Field and Federal Agency

Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate funding in one field (e.g., Department of Health and Human Services [HHS] and the U.S. Department of Agriculture in the life sciences and the Department of Energy [DOE] in the physical sciences). Other agencies—NSF, NASA, and DOD—have much more diversified funding patterns. (See figure 5-6 and appendix table 5-10.) Although an agency may place a large share of its funds in one field, it may not be an important contributor to that field, particularly if it is a small funding agency. (See figure 5-7 and appendix table 5-11.) NSF is the lead funding agency in the physical sciences (33 percent of total funding), the mathematical sciences (59 percent), and the environmental sciences (49 percent). DOD is the lead funding agency in the computer sciences (58 percent) and in engineering (45 percent). HHS is the lead funding agency in the life sciences (85 percent), the social sciences (47 percent), and psychology (86 percent). Within S&E subfields, other agencies take the leading role—DOE in physics (41 percent) and NASA in astronomy (64 percent) and in aeronautical/astronautical engineering (59 percent).

Figure 5-5.
Academic R&D expenditures, by field



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current to constant 1987 dollars.

See appendix table 5-6.

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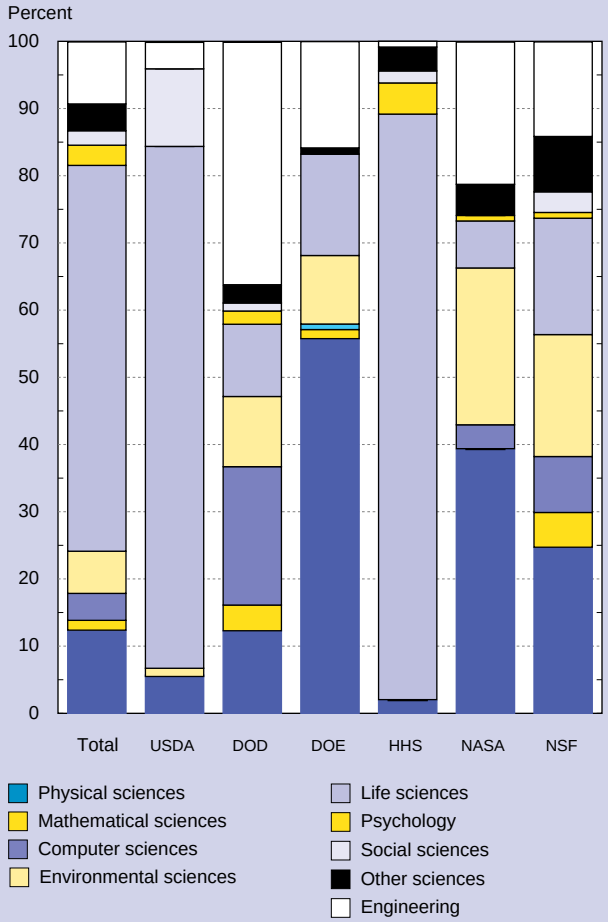
Figure 5-6.
Average composition of Federal agency academic research obligations, by field of science: FYs 1993–95



NOTES: Data for FY94 and FY95 are estimates. The six agencies reported represent approximately 97 percent of Federal academic research obligations.

See appendix table 5-10.

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The Spreading Institutional Base of Federally Funded Academic Research and Development[13]

The increase, which began in the early 1970s, in the number of academic institutions receiving Federal support for their R&D activities has continued in recent years.[14] The number of institutions receiving R&D support—which increased from 567 in 1971, to 621 in 1981, and to 772 in 1991—increased further to 827 in 1992 and to 875 in 1993. As in the earlier 1971–91 period, there was almost no change in the number of Carnegie research or doctorate-granting institutions receiving Federal R&D obligations between 1991 and 1993 (from 231 to 232). Almost the entire increase in the number of supported institutions occurred in the other Carnegie classifications—that is, among comprehensive, liberal arts, 2-year community, junior, technical, professional, and other specialized schools (from 541 to 643).[15] (See text table 5-1.)

[13]The data in this section were drawn from the Federal Support to Universities, Colleges, and Selected Nonprofit Institutions Survey. The survey collects data on Federal R&D obligations to individual U.S. universities and colleges from the 15 Federal agencies that account for virtually all such obligations.

[14]See *Science and Engineering Indicators—1993* (NSB, 1993) for a more comprehensive discussion of the spreading institutional base, which includes developments in individual fields of science and engineering. The field analysis could not be extended because DOD no longer provides detailed academic R&D funding by science and engineering field. Also see Geiger and Feller (1995).

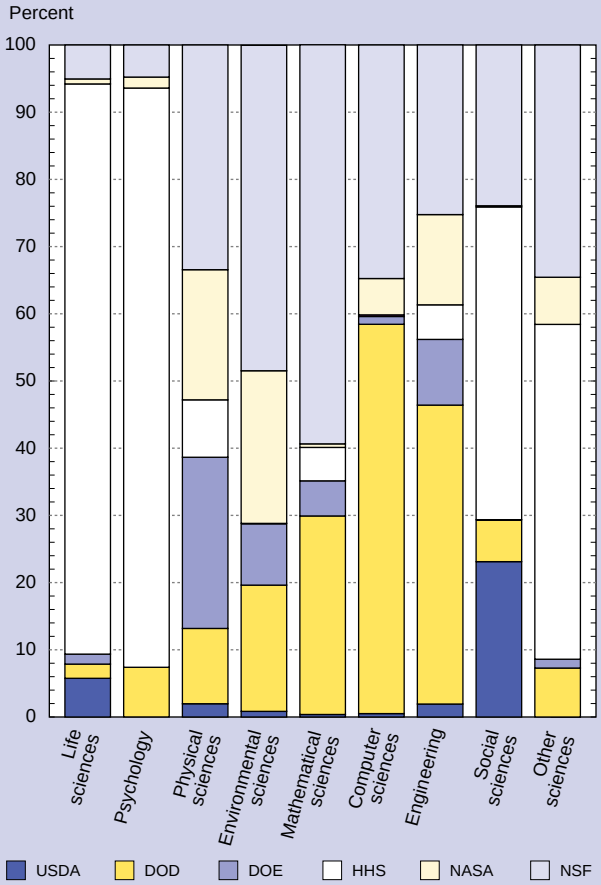
[15]See Chapter 2, Classification of Academic Institutions, for a brief description of the Carnegie categories. The classification scheme was revised in 1994 by the Carnegie Foundation for the Advancement of Teaching.

Physical Infrastructure for Academic Research and Development

This section focuses on several aspects of academic R&D facilities and instrumentation.[16] Excellent research facilities and high-quality research equipment are essential to enable U.S. academic researchers to carry out world-class research. Creative and innovative ideas may remain unexplored if the physical infrastructure neces-

[16]Data on facilities and instrumentation are taken primarily from several surveys supported by NSF. Although terms are defined specifically in each survey, in general, facilities expenditures: (1) are classified as "capital" funds; (2) are fixed items such as buildings; (3) often cost millions of dollars; and (4) are not included within R&D expenditures, as reported here. Equipment and instruments (the terms are used interchangeably) are generally movable, purchased with current funds, and included within R&D expenditures. Because the categories are not mutually exclusive, some large instrumentation systems could be classified as either facilities or equipment.

Figure 5-7.
Average percentage of Federal academic research obligations provided by major Federal agencies, by field of science: FYs 1993–95



NOTES: Data for FY94 and FY95 are estimates. The six agencies reported represent approximately 97 percent of Federal academic research obligations.

See appendix table 5-11.

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sary for their pursuit is not available. This section begins with an examination, both at the aggregate and the field-of-science level, of the quantity of research space, the levels of investment, the sources of funds, the condition and adequacy of research space, and a measure of unmet needs.[17] Following are discussions of research instrumentation expenditures and funding sources and the characteristics of the instrumentation stock. In addition, special attention is focused on computer use in research at academic institutions, particularly on the availability of data and information on this growing phenomenon.

[17]Some indicators such as those referring to the condition and adequacy of research space are, by necessity, based on the subjective judgment of the university respondents.

Text table 5-1.
Number of academic institutions receiving Federal R&D support, by type of institution

	All academic institutions	Carnegie research and doctorate-granting institutions	Other Carnegie institutions
1971	567	227	340
1981	621	227	394
1991	772	231	541
1992	827	232	595
1993	875	232	643

NOTES: See chapter 2, Higher Education in Science and Engineering, for information on the institutional categories used by the Carnegie Foundation for the Advancement of Teaching. "Other Carnegie institutions" are all Carnegie-classified institutions except research and doctorate-granting institutions.

SOURCES: Science Resources Studies Division (SRS), National Science Foundation, *Federal Support to Universities, Colleges, and Nonprofit Institutions, Fiscal Year 1993, Detailed Statistical Tables,* NSF 95-331 (Arlington, VA: NSF, 1995); and SRS, unpublished tabulations.

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An Overview of Academic Research and Development Facilities[18]

Between 1988 and 1994, total academic science and engineering research space increased by almost 14 percent, from about 112 million to 127 million net assignable square feet.[19] (See appendix table 5-12.) Planned construction outlays for academic research facilities are expected to reach $3.0 billion (in constant dollars) in 1994–95, up from $2.8 billion in 1992–93, just below $3.1 billion in 1990–91, and up from $2.7 billion in 1988–89 and $2.4 billion in 1986–87. (See appendix table 5-13 for the current dollar values.)

New construction projects initiated between 1986 and 1993 produced over 43 million square feet of new research space—the equivalent of about 34 percent of estimated existing research space. The total amount of research space has been increasing only by about half as much as new construction, indicating that a significant portion of new research space may be replacing obsolete or inadequate space rather than adding to existing space. Planned new construction projects initiated in 1994–95 are expected to produce over 11 million square feet of new research space. (See appendix table 5-12.)

Planned outlays for major repair/renovation (costing over $100,000) of academic research facilities are expected to reach $978 million (in constant dollars) in 1994–95; compared with $837 in 1992–93; $861 in 1990–91; $1,090 in 1988–89; and $971 in 1986–87. (See appendix table 5-13 for the current dollar values.)

[18]For more detailed data on and analysis of academic S&E research facilities (e.g., by institution type and control) see SRS (1994b, c).

[19]Throughout this section, research space refers to the net assignable square footage of space within research facilities (buildings) in which research activities take place. Multipurpose space, such as an office, is prorated to reflect the proportion of use devoted to research activity.

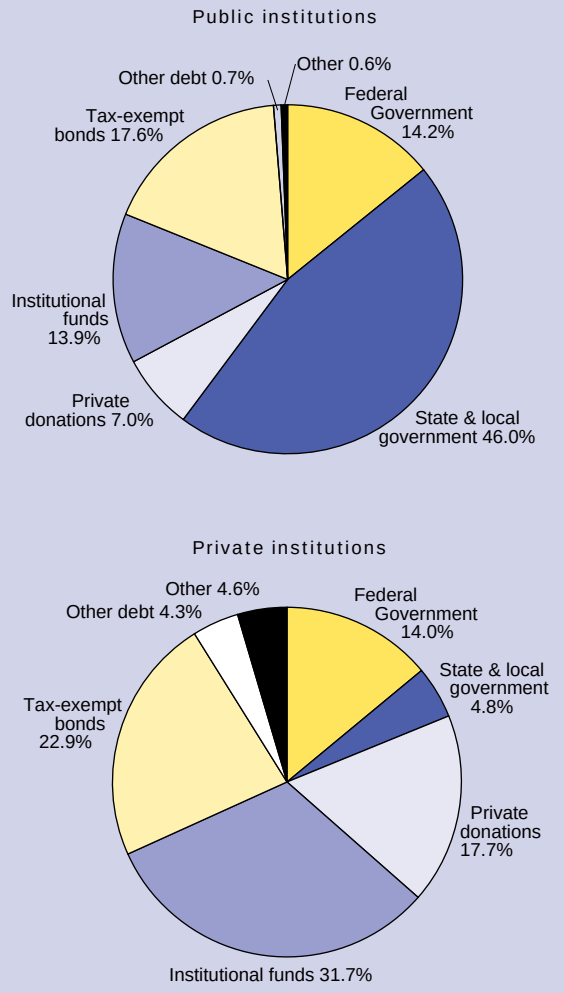
Expenditures for smaller S&E research facility repair/renovation projects (costing less than $100,000) increased by two-thirds, from $152 million in 1990–91 to $241 million in 1992–93. The repair/renovation projects initiated between 1986 and 1993 resulted in the repair/renovation of over 43 million square feet of research space or the equivalent of about 34 percent of existing research space. However, a portion of this space, particularly at the repair end, could have been counted 2 or 3 times because the same space could have been repaired/renovated several times over the course of time. The data do not differentiate between repair and renovation, nor do they permit the estimation of an actual count of unique square footage that has been repaired or renovated. Planned projects initiated in 1994–95 are expected to result in the repair/renovation of an additional 9.2 million square feet of research space. (See appendix table 5-12.)

Sources of Funds

Since 1986, there have been shifts in the importance of different sources of funds for the construction and repair/renovation of S&E research space. Funds from Federal sources[20] and from tax-exempt bonds grew in importance, with the former increasing from 6 percent in 1986–87 to 14 percent in 1992–93 and the latter from just below 16 percent to just above 19 percent. Funds from private donations diminished in importance and fell from 20 to 10 percent of total funding. However, the major sources of funds for new construction generally are not the same as those for repair/renovation. In 1992–93, about 34 percent of the funds for new construction came from state and local governments, 22 percent came from tax-exempt bonds, and 16 percent came from Federal sources. In contrast, about 40 percent of the funds for repair/renovation came from institutional funds, with another 30 percent from state and local funds. (See appendix tables 5-14 and 5-15.)

Public and private institutions draw upon substantially different sources to fund the construction and repair/renovation of S&E research space. Public institutions rely primarily on state and local funding, which accounted for 46 percent of their total funding in 1992–93 and on tax-exempt bonds, which accounted for 18 percent. Private institutions rely primarily on institutional funds, tax-exempt bonds, and private donations, which accounted for 32 percent, 23 percent, and 18 percent, respectively, of their total funding in 1992–93. (See figure 5-8.)

Figure 5-8.
Funding sources for new construction and repair/renovation of S&E research space for public and private academic institutions: 1992–93



S&E = science and engineering

See appendix tables 5-14 and 5-15.

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Condition and Adequacy

Only modest changes in the condition of academic S&E research space occurred between 1988 and 1994. (See text table 5-2.) Specifically, the percentage of space available for use in the most scientifically sophisticated research increased from 24 percent to 26 percent; the percentage effective for most, but not the most scientifically sophisticated, uses declined from 37 percent to 33 percent; the percentage of space needing limited repair/renovation remained about the same at 23 percent; and the percentage requiring major repair/renovation or replacement increased from 16 percent to 17 percent. (See appendix table 5-16.)

Unmet Needs

Determining what universities and colleges need with regard to S&E research space is a complex matter. To measure real as opposed to speculative needs, the 1994 facilities survey adopted a new approach to this issue.

[20]The actual amount of Federal funds devoted to construction and repair/renovation is underrepresented because institutional funds include indirect cost reimbursement from Federal grants to universities and colleges.

Text table 5-2.
Condition of academic science and engineering research facilities

Condition of research facilities	1988	1990	1992	1994
	Percentage of institutions' S&E research space			
All space	100.0	100.0	100.0	100.0
Suitable for use in most scientifically sophisticated research	23.9	25.9	26.8	26.4
Effective for most uses, but not most scientifically sophisticated	36.8	35.3	34.7	32.8
Requires limited repair/renovation to be used effectively	23.5	23.3	22.6	23.1
Requires major repair/renovation to be used effectively[1]	15.8	15.5	12.8	12.9
Requires replacement[2]	NA	NA	3.1	4.1

S&E = science and engineering; NA = not available

NOTES: Details may not add to totals because of rounding.

[1]The data for 1988 and 1990 in this category include space requiring replacement.

[2]This category was first used in the 1992 survey.

See appendix table 5-16.

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Institutions were asked to report whether an approved institutional plan existed that included any deferred space requiring new construction or repair/renovation. Using a strict set of standards,[21] respondents were then asked to estimate the construction and repair/renovation costs of such projects for each S&E field. The strength of this approach was that institutions had to decide how to distribute scarce resources to develop and approve plans; they were not simply making wish lists.

A total of 40 percent of all research-performing universities and colleges had an approved institutional plan that included either construction or repair/renovation projects that were deferred and unfunded.[22] The estimated cost of these projects was $5.7 billion: $4.0 billion for new construction and $1.7 billion for repair/renovation.

Academic Research and Development Facilities, by Field of Science and Engineering

There was little change in the distribution of academic research space across fields of science and engineering between 1988 and 1994. More than 90 percent of current academic research space continues to be concentrated in six S&E fields (see appendix table 5-12):

- Biological sciences (21 to 22 percent),[23]
- Medical sciences (17 to 18 percent),
- Engineering (14 to 16 percent),
- Agricultural sciences (16 to 16 percent),
- Physical sciences (14 to 13 percent), and
- Environmental sciences (6 to 6 percent).

The percentage of net assigned square feet of research space either newly constructed or renovated between 1986 and 1993 differs across fields of science and engineering. In the medical sciences, computer sciences, physical sciences, and engineering, as much as two-thirds of research space may have been built or repaired/renovated in the 1986–93 period.[24] In contrast, no more than 50 percent of the research space for social sciences, mathematics, agricultural sciences, and psychology was newly constructed or repaired/renovated during this period. (See figure 5-9.)

Condition and Adequacy

The condition of academic research space also differs among S&E fields. In 1994, a higher percentage (22 percent) of the total S&E research space in the agricultural sciences needed major repair/renovation or replacement than in any other field. Fields in which more than 17 percent (the average for all S&E fields) of the total S&E research space needed major repair/renovation or replacement included the physical sciences (18 percent), the environmental sciences (19 percent), and the biological sciences outside of medical schools (19 percent). In contrast, major repair/renovation or replacement was needed in only 13 percent of the total S&E research space in psychology, 11 percent in the social sciences, and less than 6 percent in both mathematics and the

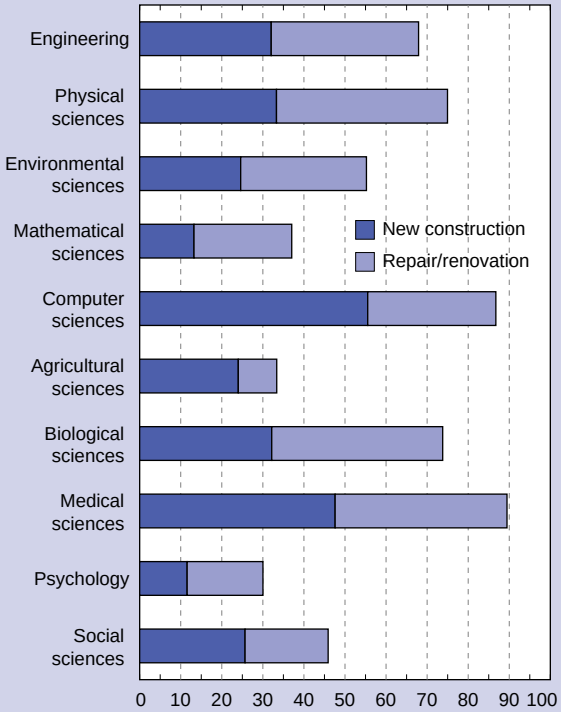
[21]Four criteria were used to define deferred space: (1) The space must be necessary to meet the critical needs of current faculty or programs; (2) construction must not be scheduled to begin during 1994–95; (3) construction must not currently have funding; and (4) the space must not be utilized for developing new programs or for expanding the number of faculty.

[22]The other 60 percent of the institutions could have had a "need," but they did not have an approved institutional plan. Certain classes of institutions (e.g., smaller institutions and historically black colleges and universities) were less likely to have a plan or one that included deferred needs. The top 100 institutions (in terms of research expenditures) were most likely (60 percent) to have an approved institutional plan, and the non-doctorate-granting institutions were least likely (26 percent) to have one.

[23]Within the biological sciences, there was a significant shift in the location of research space among universities, colleges, and medical schools during this period. In 1988, slightly less than 33 percent of this space was located at medical schools; by 1994, 39 percent of the space was in medical schools.

[24]As noted earlier, the actual percentage of existing space repaired/renovated is not known because some space may have been repaired/renovated more than once. Consequently, the numbers reported for the percentage of net assigned square feet of research space repaired/renovated between 1986 and 1993 are upper bounds.

Figure 5-9.
Percentage of research space newly constructed and repaired/renovated between 1986 and 1993, by S&E field: 1994



S&E = science and engineering

NOTE: The actual percentage of existing space that was repaired/renovated is not known because some space may have been renovated more than once. The percentages displayed above for the space repaired/renovated between 1986 and 1993 are upper bounds.

See appendix table 5-12.

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computer sciences. At this point, there are no evident trends in repair/renovation needs across S&E fields. (See appendix table 5-16.)

Universities and colleges were more likely to rate research space as inadequate in some S&E fields rather than in others.[25] Forty percent or more of all institutions indicated inadequate amounts of S&E research space in engineering, the physical sciences, the biological sciences outside of medical schools, and the medical sciences in medical schools. In contrast, one-third or less of all institutions indicated inadequate amounts of S&E research space in the environmental sciences, the agricultural sciences, mathematics, psychology, and the social sciences. (See appendix table 5-17.)

[25]Respondents were asked to rate the amount of research space in each field by choosing one of the following: (1) adequate amount (sufficient to support all the needs of your research in the field); (2) generally adequate amount (sufficient to support most of your research needs in the field but may have some limitations); (3) inadequate amount (not sufficient to support the needs of your research in the field); (4) nonexistent space but needed; or (5) not applicable or not needed. Inadequate space is defined as either category 3 or category 4.

Unmet Needs

Deferred and unfunded need existed in all S&E fields. Unfunded need for new construction projects in the agricultural sciences was indicated more frequently than in any other field. Slightly over one-fifth of all responding institutions with research space in the agricultural sciences reported unfunded need for new facilities in this field. Four other fields were mentioned by at least 10 percent of the responding group: engineering (18 percent); the physical sciences (16 percent); the medical sciences in medical schools (16 percent); and the biological sciences outside the medical schools (14 percent). Unfunded need for repair/renovation projects in the physical sciences was indicated more frequently than in any other field. Over 20 percent of responding universities and colleges reported unfunded need for repair/renovation in four fields: the physical sciences (25 percent); engineering (22 percent); the biological sciences outside of medical schools (22 percent); and agricultural sciences (21 percent). (See text table 5-3.)

Instrumentation Expenditures and Funding Sources[26]

Current fund expenditures for academic research instrumentation grew at an average annual rate of about

[26]Data used here from the Survey of Scientific and Engineering Expenditures at Universities and Colleges are limited to current fund expenditures for research instrumentation and do not include funds for instructional equipment. Current funds—as opposed to capital funds—are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

Text table 5-3.
Percentage of institutions with deferred capital projects to construct and/or repair/renovate S&E research facilities, by field: 1994

Field	Construction	Repair/ renovation
Physical sciences	16	25
Mathematical sciences	3	11
Computer sciences	4	9
Environmental sciences	9	13
Agricultural sciences	21	21
Biological sciences		
In universities and colleges	14	22
In medical schools	5	9
Medical sciences		
In universities and colleges	9	10
In medical schools	16	14
Psychology	4	8
Social sciences	5	8
Engineering	18	22

NOTE: Percentage above corresponds to percentage of all responding institutions with research space in the relevant S&E field (including those without plans).

SOURCE: Science Resources Studies Division, National Science Foundation, *Scientific and Engineering Research Facilities at Universities and Colleges: 1994 Volume II, Detailed Statistical Tables*, NSF 94-316 (Arlington, VA: NSF, 1994).

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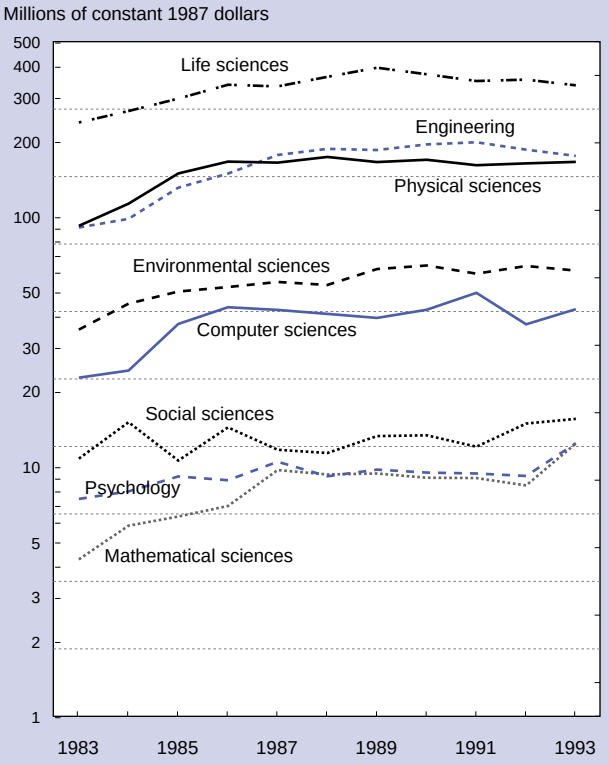
8.5 percent between 1983 and 1989 before beginning a steady decline of 2 percent a year from 1990 through 1993 (in constant 1987 dollars). (See appendix table 5-18.) Research instrumentation expenditures grew for all S&E fields during the 1983–89 period. The slowest growth was in the life sciences (5.9 percent) and the social sciences (6.3 percent). The fastest growth was in the mathematical sciences (19.5 percent), engineering (11.6 percent), computer sciences (11.1 percent), and the physical sciences (10.3 percent). Since 1989, however, all S&E fields grew at average annual rates of 2 percent or below, except the mathematical sciences (at 7.2 percent), psychology (at 6.3 percent), and the social sciences (at 4.1 percent). Engineering, the life sciences, and the environmental sciences showed declining expenditures, and the physical sciences showed zero growth. (See figure 5-10.)

Between 60 and 64 percent of these expenditures were covered by the Federal Government in the 1983–89 period. The Government's share fell to below 60 percent between 1990 and 1992 before it increased slightly to just above 61 percent in 1993. This percentage varied among individual fields, however, with the social sciences receiving between 28 and 43 percent of their research equipment funds from the Federal Government and the physical sciences, computer sciences, mathematical sciences, environmental sciences, and psychology receiving over 60 percent.

Although current annual funds for research equipment expenditures fluctuated between 5 and 7 percent of total R&D expenditures during the 1983–93 period, this percentage has declined every year since 1986 (from 7.2 to 5.2 percent). Although such a monotonic decline in the share of R&D expenditures for research equipment did not occur in all the S&E fields, the 1993 percentage was below that of 1986 in every field, except for the mathematical sciences. With respect to the level of equipment purchases as a percentage of R&D expenditures, this percentage was consistently higher than average in the computer sciences, physical sciences, and engineering and was consistently lower in the social sciences, life sciences, psychology, and mathematical sciences (except for 1993).

Figure 5-10.
Current fund expenditures for research equipment at academic institutions, by field



NOTE: See appendix table 4-1 for GDP implicit price deflators used to convert current collars to constant 1987 dollars.

See appendix table 5-18.

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Characteristics of Academic Research and Development Instrumentation[27]

Annual expenditures for the purchase of research instruments increased in current dollars in each of the four cycles of the instrumentation survey, but in 1993 the data show a decrease in constant dollars from the 1988–89 survey.[28] Expenditures for the repair and maintenance of research instruments also increased in every survey through 1988–89, but in 1993 they decreased in both current and constant dollars. Beginning with the 1988–89 survey, data on expenditures for the operation of research instruments also have been collected, and the 1993 data on expenditures show a decrease from the 1988–89 survey. The maintenance, repair, and operation of existing equipment represent a considerable expense for research

[27]NSF, with funding from NIH, initiated the National Survey of Academic Research Instruments and Instrumentation Needs in 1983–84. The survey's first three cycles (covering 1982–83, 1985–86, and 1988–89) collected data on S&E fields in two phases: Data for engineering, the computer sciences, chemistry, and physics/astronomy were collected in the cycle's first year; and data for agriculture, biology, and the environmental sciences were collected in the cycle's second year. In the survey's most recent cycle, the two data-collection phases were consolidated to cover all fields in the same year. Also, in previous cycles, each survey cycle included: (1) department questionnaires requesting department expenditures for equipment and related issues, such as equipment needs and priorities, and (2) instrument data sheets for information on the condition, cost, usage, etc., of specific equipment. Beginning in the fourth cycle, the department questionnaire was conducted every other year and the instrument data sheets, every fourth year. Only the department questionnaire survey data for the fourth cycle are reported here.

[28]Data on expenditures for research equipment purchases obtained through this instrumentation survey cannot be readily compared with those discussed in the previous section, because they were based on the annual R&D Expenditures survey. The instrumentation survey data here include all expenditures—both from current operating funds and capital accounts. In the previous section, the discussion was limited to data on research equipment from current funds expenditures, which could be a considerably smaller expenditure. Both of these data sources, however, indicate that expenditures for instrumentation have decreased, in constant dollars, in recent years.

units. In 1993, for every $1 spent on purchasing research equipment, an additional $.19 was spent on maintenance and repair, and $.47 was spent on operation.

The instrumentation survey gathers data on the current adequacy of, and future needs for, instrumentation. Respondents to the survey (department chairs and heads of research facilities) reported continuing needs for instrumentation for their units. Sixty-nine percent of respondents in 1993 reported that their needs had increased over the previous 2-year period. Thirty percent said their needs had remained about the same, while only 2 percent reported that needs in their units had decreased.

In 1993, 58 percent of the respondents rated the capability of their instruments to satisfy the major research needs of their faculty as adequate to excellent. However, in an indication of continuing needs, 39 percent of the respondents—the modal response—rated the overall capability of their instrumentation as inadequate to support the research needs of their faculty.

Nevertheless, the level of investment in research instrumentation over the past decade appears to have produced beneficial results for many academic departments and research facilities. For example, since 1982–83 there has been a steady decline in the percentage of respondents reporting that there were subject matters in which investigators could not perform critical experiments because needed equipment was lacking. Although a majority (56 percent) of all respondents still reported inadequate instrumentation in 1993, it represented a decline from the 74 percent of respondents who reported this limitation in the 1982–83 survey, and a further decrease from the 61 percent who reported it in the 1988–89 survey.

Use of Computers in Academic Research and Development

It is difficult to find recent information about the use of computers in academic R&D. Many of the current surveys on research instrumentation concentrate on expenditures at the department level; therefore, purchases of computers used for research are most likely reported as expenditures for these disciplines (e.g., physics or chemistry) and not as computer expenditures. However, results of two recent surveys provide some indirect information about computer use in research or by academic researchers. The NSF/NIH National Survey of Academic Research Instruments and Instrumentation Needs (the instrumentation survey discussed above) provides some information about shifts that appear to have occurred in the nature of the use of computers in academic research. The U.S. Department of Education's 1993 National Study of Postsecondary Faculty Survey provides information about faculty ratings of the quality of computer equipment and the number of research faculty with access to (or knowledge of) computer resources at their institutions.

The instrumentation survey collects instrument-related data from a sample of academic science and engineering departments and nondepartmental research facilities. Beginning with the 1988–89 survey, data were collected from both computer science departments and computer science facilities at a sample of 55 colleges and universities and 24 medical institutions. Differences in the expenditure data reported since the 1988–89 survey suggest that there has been a change in the structure in which computers are used in research at U.S. academic institutions.

As a result of a 35-percent decline in expenditures for research instrumentation, as reported by computer science units (departments and facilities) in the 1992 survey, follow-up analyses were conducted to understand the data more fully. These analyses supported the initial findings of the survey that the decline in expenditures for research equipment between 1988 and 1992 occurred only in computer research facilities and did not occur in computer science departments.[29] The analyses suggest that the decline in expenditures for the purchase of research equipment by computer science units is due to the existence of fewer large, centralized computer facilities devoted to research activities. The 1993 survey shows that expenditures in computer science departments continued to increase, while expenditures in computer science facilities continued to decline.

At present, no recent data are available to directly assess the reasons for the decline in the number of centralized computer facilities used for research at academic institutions. However, in the years since the 1988–89 survey was conducted, the computational powers of computers have sharply increased while their cost has dramatically declined. The instrumentation survey's follow-up analyses suggest that this fundamental change in computing instruments, coupled with the rapid increase in networking access to off-site research computing power, has allowed many administrators to move computer support for research away from an emphasis on large mainframe computers on each campus. Instead, focus increasingly has been on the purchase of many smaller and cheaper but very powerful computers now in the laboratories and offices of the researchers themselves, thus making computer access more responsive to their needs.

A further indication of this change in research-equipment ownership patterns comes from a "needs assessment" question in the instrumentation survey. The department chairs and heads of facilities were asked to describe the topmost priority for research instrumentation in their units and to give the approximate cost of acquiring that instrument. As an indication of the importance of computers to research in all fields, 29 percent of all respondents listed some type of computer as their topmost priority instrument. The extent of top priority need for computers varied from highs of 99 percent for com-

[29]The decline appears to have occurred because a significant number of these facilities were beyond the scope of the survey in 1992. They were ineligible because they no longer existed, were not used for research, or did not have any research equipment originally costing at least $20,000 (a survey design minimum beginning in 1992). Radical design and price changes for computer equipment may confound any analysis of trends in the use of computers.

puter science, 37 percent for engineering, and 35 percent for the environmental sciences respondents, to a low of 14 percent for the chemistry respondents. The cost to acquire the top-priority computers was $202 million or 21 percent of the total cost of all first-priority items.

In a related finding in the faculty survey, faculty, particularly S&E Ph.D. research faculty, had substantial access to computing capability, especially personal computers, at their institutions. Faculty members were asked to rate a number of facilities and resources at their institutions that were available for their own use during the 1992 fall term. These resources included personal computers, centralized (mainframe) computer facilities, and computer networks with other institutions. There were five possible ratings: not available/not applicable, very good, good, poor, and very poor. Thus, the data from this survey provide information not only about faculty perceptions of the quality of the three types of computer resources, but also about the extent to which faculty had access to (or knowledge of the quality of) these resources.

The survey indicates that faculty members with S&E Ph.D. degrees and with research as their primary activity were most likely to have access to high-quality (rated good or very good) computing power. Over 96 percent of this group had access to a personal computer, over 87 percent to a centralized computer facility, and about 86 percent to computer networks with other institutions. About 87 percent of this group rated the personal computers at their institutions as good or very good; 71 percent had access to good or very good centralized computer facilities; and 71 percent also had access to good or very good computer networks with other institutions. This group of Ph.D. faculty researchers were more likely to have access to both all three types of computing facilities and to higher-quality computing facilities than faculty who were less active in research, had a non-S&E Ph.D. degree, or did not have a Ph.D. degree at all. Nevertheless, a very high percentage of all faculty had access to computing facilities on their campuses. (See text table 5-4.) About 91 percent of all full-time faculty members had access to a personal computer at their institution—71 percent to a high-quality personal computer. About 78 percent of this group had access to centralized computer facilities—61 percent to a high-quality centralized computer facility. About 73 percent also had access to computer networks with other institutions—about 50 percent to high-quality computer networks with other institutions.

Text table 5-4.
Full-time faculty's rating of computer equipment, by type of faculty and equipment: 1994

Type of full-time faculty	Personal computers	Centralized computer facilities	Computer networks with other instns
"Good" or "very good" rating			
		Percent	
S&E doctoral faculty with research as primary activity	87.0	71.2	71.2
S&E doctoral faculty who do some research	80.4	70.7	66.3
All S&E doctoral faculty	79.8	69.6	64.9
All doctoral faculty	75.9	67.2	60.5
All faculty	71.3	61.3	50.4
"Not available/not applicable" rating			
S&E doctoral faculty with research as primary activity	3.7	12.7	13.7
S&E doctoral faculty who do some research	4.9	14.3	16.4
All S&E doctoral faculty	5.5	15.2	17.5
All doctoral faculty	6.6	17.5	19.9
All faculty	8.6	21.7	26.6

NOTE: Choices for ratings were "not available/not applicable," "very poor," "poor," "good," and "very good."

SOURCE: Office of Educational Research and Improvement, National Center for Educational Statistics, U.S Department of Education, *1993 National Study of Postsecondary Faculty*, unpublished tabulations.

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Human Infrastructure for Academic Research and Development

This section discusses trends in the employment and characteristics of academic science and engineering doctorate holders, with a short discussion on nondoctorates. (Two different data sources have been used for this section. See *Data Sources: Nature, Problems, and Comparability* for a discussion of the surveys.) The central focus is on academic researchers—those who report that research is part of their work responsibility[30]—their number and characteristics, including field of degree, age, sex, race/ethnicity, and the extent of Federal support. Trends are examined in the reported primary work responsibility for research or teaching of S&E doctorates in regular faculty positions. The interplay between teaching and research responsibilities is discussed and examined separately for major research universities and other institutions. Data are presented on the participation of graduate research assistants in academic R&D. The section concludes with a discussion of the faculty age structure.[31]

[30]Data on doctoral scientists and engineers are derived from two sample surveys. The biennial SDR, conducted for NSF by the National Research Council (NRC), covers science and engineering doctorate holders with degrees from U.S. institutions. The NSPF, conducted by the Department of Education's National Center for Education Statistics in 1988 and 1993, has broader field coverage and includes faculty at all degree levels. Data have been extracted from NSPF to approximate the SDR sample definitions. Estimates of academic doctoral employment for scientists and engineers agree very well with one another, as do estimates of doctoral researchers. Accordingly, NSPF data are used here to extend the analysis to nondoctorate researchers and to characterize researcher's teaching activities at the undergraduate and graduate levels. Excluded from this discussion are 6,100 S&E doctorates employed in university-managed FFRDCs.

[31]*All data derived from the SDR are preliminary and subject to revision before this volume goes to print.* The Survey of Doctorate Recipients (SDR), on which much of this section is based, underwent major changes in 1991 and 1993, making data from these years not strictly comparable with earlier estimates. Consequently, figures reported

Academic Scientists and Engineers

In 1993, U.S. universities and colleges employed 212,900 doctoral scientists and engineers, or 46 percent of the 465,800 employed in all sectors. (See appendix table 5-19.) Academic doctoral S&E employment was heavily concentrated in universities, medical schools, and 4-year colleges; only a small number of S&E Ph.D.s held positions in junior colleges. In the 4-year institutions, S&E employment included an additional 66,000 professional degree holders (almost all in the health sciences and of whom about 15 percent also had a doctorate degree) and 61,300 with a master's or bachelor's degree (chiefly in the life sciences, social sciences, mathematics, and engineering). (See text table 5-5.) Seventy percent of the latter held faculty appointments, though generally not in the major research universities. In some fields, notably the life sciences and engineering, they were actively involved in research.

The structure of academic employment changed gradually over the past 2 decades. (See figure 5-11.) Ph.D.s in traditional, full-time faculty positions[32] (171,800 in 1993) accounted for 81 percent of all doctoral academic scientists and engineers; 2 decades earlier, their fraction had been 90 percent. The shift resulted from somewhat faster growth in the number of full-time appointments outside the traditional faculty track, including postdoctorates,[33] which rose from 8 to 16 percent. The part-time share fluctuated between 2 and 3 percent over the period. (See appendix table 5-20.)

here are rounded; only full percentages are reported, and modest changes should be discounted. For more detail, the reader should consult *Data Sources: Nature, Problems, and Comparability.*

[32]Faculty are defined by rank and include full, associate, and assistant professors and instructors.

[33]There is some evidence that responses to the postdoctorate question in SDR have been inconsistent over time. Apparent fluctuations in this series should be treated with caution. See also NRC (1995) and NAS (1995).

Academic Research Personnel[34]

In 1993, approximately 149,800 doctoral scientists and engineers were engaged in academic R&D, along with 10,500 who held professional degrees and 5,500 with S&E degrees at the master's and bachelor's levels. (See appendix table 5-19 and text table 5-5.) For doctoral scientists and engineers, this represents an increase of about two-thirds, compared with the 38-percent increase in employment since 1979. In fact, during the 1980s, a growing proportion of academic doctoral scientists and engineers had reported that research was their primary or secondary work responsibility, suggesting that the academic S&E workforce had become more research intensive in this sense. A comparison of earlier data with those from 1989, 1991, and 1993,[35] however, suggests that this trend did not continue, but leveled off and may have changed direction.

The highest levels of research participation (76 to 79 percent) were reported by engineers and by life, environ-

[34]The number of doctoral academic researchers was determined from SDR, based on responses to a question about primary and secondary work activity. In 1991, this question asked: "From the activities listed below, select your primary and secondary work activities…in terms of time devoted during a typical week." In 1993, it was determined from the two activities that reportedly took most of the weekly work time. Because many faculty members who devote a substantial amount of time to R&D often consider another activity (e.g., teaching) as their primary work activity, those survey respondents who selected academic R&D as either their primary or secondary work activity are included in the discussion in this section. (For an examination of those with primary work responsibility for research, see Teaching and Research in this chapter.) The inclusion of both sets of respondents yields an amount approximately twice that when only those reporting R&D as their primary activity are counted. These headcounts should not be considered full-time equivalents. Nondoctoral S&E counts are estimated from NSPF.

[35]The comparison is only a rough one because of the significant changes in the survey procedure and content in each of these years; see *Data Sources: Nature, Problems, and Comparability.* Nevertheless, a cautious assessment has been undertaken.

Text table 5-5.
Primary work responsibility of nondoctoral academic scientists and engineers, by type of degree and field: 1993

Field	Master's and bachelor's degrees			Professional degrees		
	All	Teaching	Research	All	Teaching	Research
	Number	Percent		Number	Percent	
Science and engineering, total	61,300	72.5	9.0	66,031	35.5	15.9
Physical science	2,573	74.6	5.2	1,008	54.0	46.0
Mathematics	6,487	89.9	4.3	388	63.4	36.9
Computer science	2,953	82.6	7.9	244	100.0	0.0
Environmental science	930	89.4	0.0	196	0.0	54.1
Biology and agriculture	7,651	54.2	23.3	1,618	40.6	40.5
Medical and health science*	20,350	70.6	3.0	60,582	33.6	14.5
Psychology	4,562	71.0	12.6	402	64.9	9.7
Social science	9,316	79.6	5.6	1,080	69.4	16.2
Engineering	6,478	65.3	20.6	512	74.6	25.4

* In these fields, clinical service is the primary responsibility of 16 percent of those without a professional degree and 40 percent of professional degree holders.

SOURCES: Office of Educational Research and Improvement, National Center for Educational Statistics, U.S Department of Education, *1993 National Study of Postsecondary Faculty*; and NSF, unpublished tabulations.

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Data Sources: Nature, Problems, and Comparability

Data used in this section to describe the employment, characteristics, and activities of academic doctoral scientists and engineers derive from two sources, the Survey of Doctorate Recipients (SDR) and the National Study of Postsecondary Faculty (NSPF).

Much of the data on the academic employment and research activities are derived from SDR, a sample survey jointly sponsored by NSF and other selected Federal Government agencies and conducted biennially by the National Research Council (NRC). In 1991 and 1993, SDR underwent several design changes as part of a larger effort to redesign NSF's science and engineering personnel survey system. These changes have affected the comparability of data from 1991 and later with those of earlier years.*

Through 1989, the SDR sample included three major respondent segments: (1) persons who received Ph.D. degrees in science or engineering from a U.S. institution; (2) holders of doctorate degrees in other fields and working in science or engineering at the time of the survey; and (3) persons who earned science or engineering Ph.D.s from non-U.S. institutions. The 1991 and 1993 samples retained only those in category 1. Moreover, in an effort to improve response rates within budget constraints, sampling strata and overall sample size were reduced. Other changes were made, including a 31-month interval between the 1989 and 1991 surveys, compared with the usual 24 months. The reference period between the 1991 and 1993 surveys was 20 months.

In the 1991 and 1993 surveys, a number of changes in the data collection methods were introduced, especially the use of computer-assisted telephone interviewing. These changes resulted in much higher response rates than previously had been attained. In turn, certain patterns found in the methodological analyses of these surveys led to some reestimation of previous values. Methodological work currently in progress may lead to additional reestimation (Moonesinghe and Mitchell, forthcoming).

Definitive statistical studies remain to be completed on the overall effects of these changes on the data themselves and the range of interpretations permitted by them. Preliminary investigation suggests that the SDR survey system permits analysis of trends, if the data are limited to respondents under category 1 above. To obtain these estimates, the data in this section have been structured in accordance with suggestions offered by NRC's Office of Scientific and Engineering Personnel (OSEP). Nevertheless, the reader is advised that potentially interesting but small statistical differences should be treated cautiously.

The National Study of Postsecondary Faculty (NSPF) 1993 was sponsored by the U.S. Department of Education and other Federal Government agencies including NSF. The survey frame was based on a sample of about 31,400 faculty at 974 public and private higher education institutions. The survey covered individuals designated as faculty in these institutions, whether or not their responsibilities included instruction, and those in other (nonfaculty) positions with instructional duties. (See National Center for Education Statistics, 1994b.) The survey covered faculty at all degree levels and in all fields and gathered information on a number of items, notably teaching responsibilities and activities, that exceeded the detail available from SDR.

National estimates of doctoral scientists and engineers extracted from NSPF were found to agree with estimates derived from SDR for national totals and with results from the break down of the data by sex, field, and institution type. Accordingly, data from NSPF have been used to supplement information drawn from SDR.

*For more detail on individual surveys, see the technical notes in SRS (1995f) and the methodological volumes issued by OSEP to accompany each survey report.

mental, and computer scientists. Those in mathematics, the social sciences, and psychology reported the lowest levels, ranging from 60 to 67 percent. In general, women were somewhat less likely than men to report research responsibility. (See appendix table 5-19.)

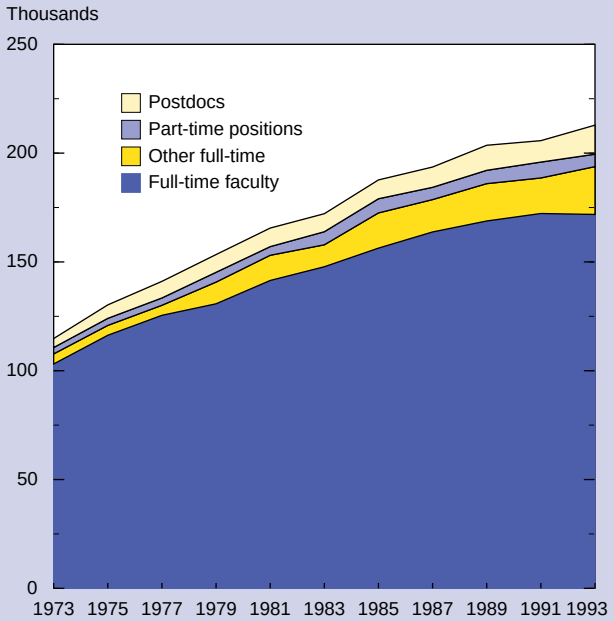
The field composition of academic doctoral researchers has changed little over the years, largely reflecting modest composition shifts in the academic workforce. In the 1993 distribution, life sciences researchers remained the largest group by maintaining their 35-percent share of the S&E total. (See figure 5-12.) The number of researchers in the physical sciences grew slightly slower than in other fields, and its share declined from 17 to 13 percent. Mathematics also lost some of its share, while the social sciences gained. (See appendix table 5-19.)

Graduate Students in Academic Research and Development

In 1993, a record 89,700 full-time S&E graduate students received their primary support from research assistantships (RAs).[36] This amounted to 27.2 percent of

[36]Chapter 2, Higher Education in Science and Engineering, contains a more detailed discussion of graduate enrollment and support in the sciences and engineering. The discussion here focuses solely on students, regardless of citizenship status, whose primary support mechanism is research assistantships from any source.

Figure 5-11.
Academic doctoral scientists and engineers, by type of position



See appendix table 5-20.

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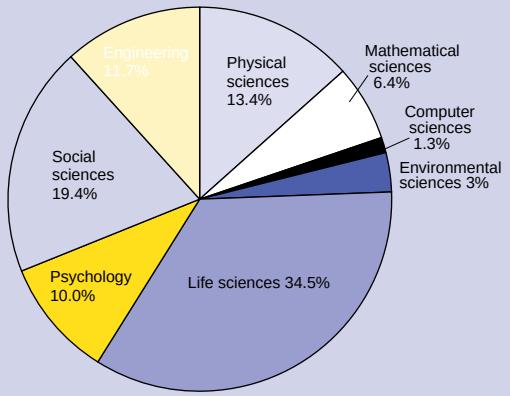
Figure 5-12.
Distribution of academic doctoral researchers, by field: 1993



See appendix table 5-19.

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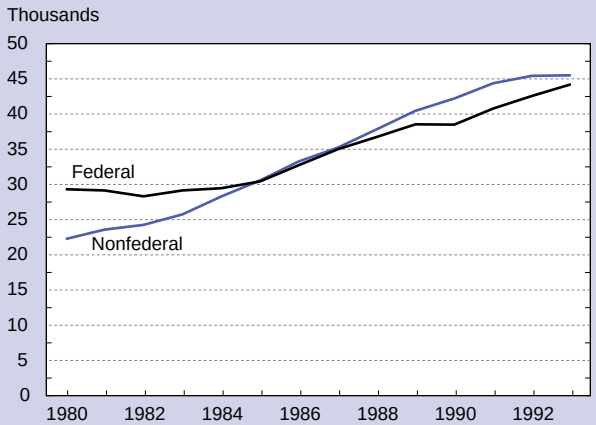
the total full-time enrollment. Barely half of these RAs (13.4 percent) were supported by Federal Government funds, the remainder (13.8 percent) received their support from other sources. (See appendix table 5-21.)

The largest number of graduate RAs was found in the life sciences and in engineering, each with nearly one-third of the total, followed by the physical and environmental sciences, with a combined share of just under 20 percent. (See appendix table 5-22.) By field, graduate RAs with Federal and nonfederal support were distributed differently. Relatively more of the nonfederal RAs were in engineering (33.3 versus 28.5 percent for federal) and in the social and behavioral sciences (19.3 versus 6.7 percent). Federal funding was more heavily concentrated in the physical and environmental sciences (27.5 versus 10.7 percent for nonfederal).

Full-time graduate enrollment grew from 238,500 in 1980 to 330,200 in 1993. Over the same period, the number of students supported by RAs grew more rapidly, from 51,600 to 89,700. At the same time, the number of RAs funded from nonfederal sources rose most rapidly and more than doubled between 1980 and 1993. Federally funded RAs also increased by 50 percent over the same period. (See figure 5-13.) Thus, the proportion of all full-time graduate students supported by federally funded RAs has essentially been stable (around 13 percent) since 1987. In contrast, the nonfederal fraction increased from just over 9 percent in 1980 to about 14 percent in 1988 and has fluctuated around that value since then. (See appendix table 5-21.)

The field distribution of graduate research assistants was not identical to that of doctoral researchers. (See figure 5-14.) Engineering and the computer sciences appear to have moved toward the extensive integration of research and education, as evidenced by their use of research assistants, while mathematics, the social sciences, and psychology made relatively little use of them. (See text table 5-6.) The computer sciences ratio may be overstated. The researcher data are based on field of degree, which, for this new field, considerably understates the number of people actually working and doing research in it. (Field of employment data are unavailable for 1993.) Data for earlier years suggest, however, that research in this field is quite graduate-student intensive, relative to other fields.

Figure 5-13.
Science and engineering research assistants supported by Federal and nonfederal sources



See appendix table 5-21.

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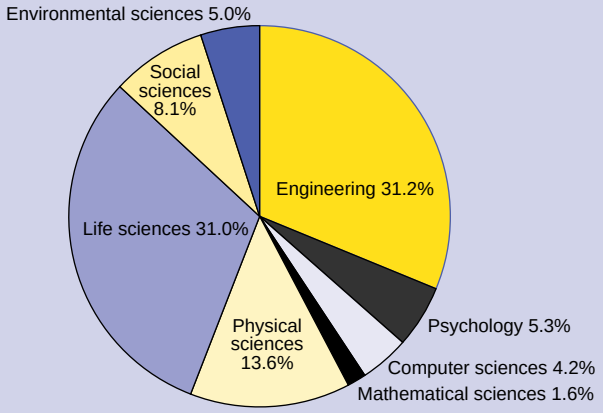
Figure 5-14.
Distribution of graduate research assistantships, by field: 1993



See appendix table 5-22.

Science & Engineering Indicators – 1996

Text table 5-6.
Graduate research assistants per 1,000 researchers, by field: 1993

Field	Research assistants	Doctoral researchers	RAs per 1,000 researchers
Science and engineering, total	89,729	149,848	599
Sciences, total	61,952	132,320	468
Physical science	12,246	20,028	611
Mathematics	1,395	9,517	147
Computer science	3,747	1,998	1,875
Environmental science	4,788	5,015	955
Life science	28,036	51,765	542
Psychology	4,500	14,931	301
Social science	7,240	29,066	249
Engineering	27,777	17,528	1,585

RA = research assistant

See appendix tables 5-19 and 5-21.

Science & Engineering Indicators – 1996

Teaching and Research

In recent years, concern has been expressed that university faculty may "unduly" be focusing on research at the expense of teaching. The extent to which faculty members who devote a substantial portion of their time to research are also engaged in teaching has become the subject of debate, especially as it relates to their involvement with undergraduates. A detailed snapshot for 1993, drawn from NSPF, addresses the question: "How do full-time doctoral science and engineering faculty with substantial research involvement allocate their time between teaching, research, and other functions, and how does their employment setting influence these patterns?"

Full-time doctoral S&E faculty members are classified by their major activity, according to the respondent's reported weekly time budget.[37] (See appendix table 5-23.) Data describe the number of students taught during the 1992 fall semester, the aggregate number of student hours, by level, and the average percentage of time spent on teaching and research, along with per-faculty averages on those measures. Data are presented separately for faculty in all types of institution and for faculty in research universities (based on the 1993 Carnegie classification).

The average faculty member (in all types of institution) spent about 44 percent of his or her weekly work time on teaching and about 32 percent on research. The faculty member taught an average of 69 students for 7 credit hours per semester (a little more than two courses). Of these, 5 credit hours were devoted to undergraduate instruction (54 students) and the remainder to graduate-level courses.

Faculty members whose major activity was research spent 59 percent of their time researching and 22 percent teaching and taught an average of one course involving 48 students (29 undergraduates and 19 graduate students, with the teaching load split fairly evenly between them). (See footnote 37.)

About 40 percent of these faculty members, however, taught one or more undergraduate course in the fall of 1992; the others had no undergraduate teaching responsibility during that period. Those who taught undergraduates spent nearly one-third of their time on teaching duties and just under half on research. In contrast, those teaching only graduate students spent 17 percent of their time teaching (averaging 2 semester hours and 26 graduate students) and 65 percent on research.

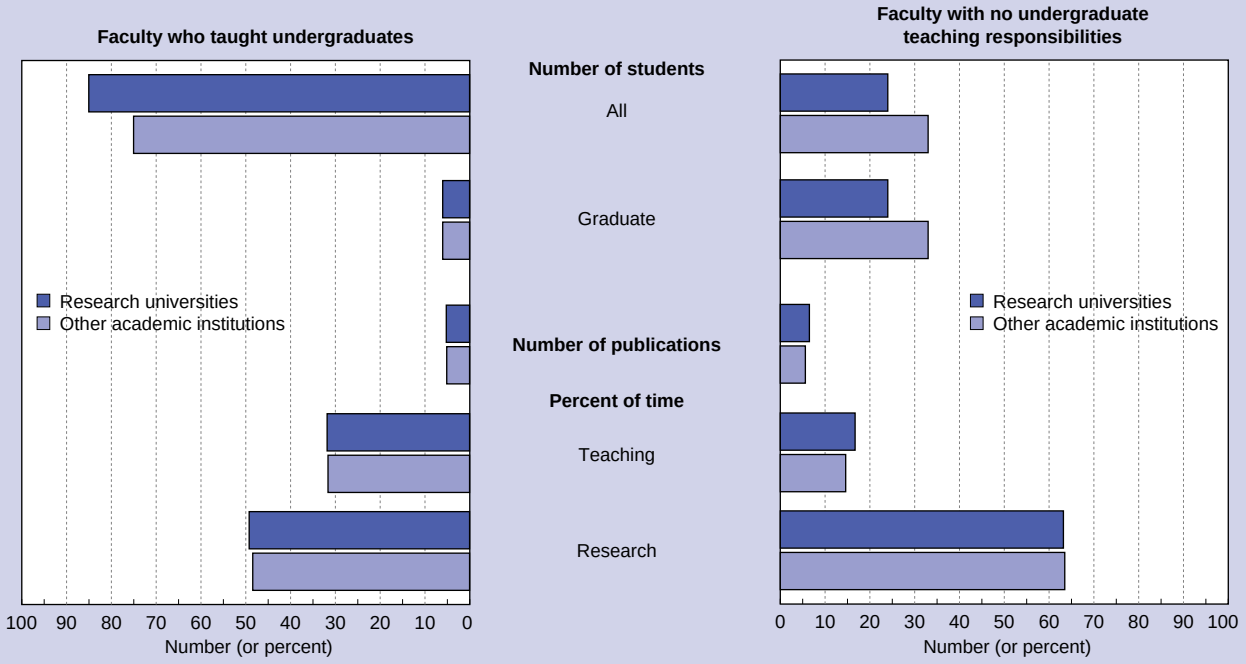
Not surprisingly, this differentiation of work responsibilities among those with substantial time investment in research had some effect on published output as well. Those with undergraduate teaching responsibilities published fewer than five articles over a 2-year period; those without wrote more than six articles.

Seventy percent of the research faculty (as defined here) were employed in research universities,[38] which raises the question of whether the observed differences could be a function of the employment setting. One could reasonably expect these faculty members' time budgets for research and teaching to differ from those of their colleagues in comprehensive institutions and 4-year colleges. Instead, surprisingly little difference existed across these institutional boundaries in the number of hours taught, size of undergraduate classes, and the

[37]Data from SDR and NSPF agree quite well when they are broken down into those primarily engaged in research, teaching, and other activities. The data discussed here are limited to full-time faculty—full, associate, and assistant professors, and instructors—since the issue is the interplay between research and teaching for those in regular faculty positions. For consistency with the 1993 SDR survey practice, major work activity was defined based on the distribution of work time, by function. In the data drawn from NSPF, those classified under research were defined as spending most time on research, plus those spending as much time on research as on teaching if both summed to more than 60 percent of weekly work time.

[38]Based on the 1994 Carnegie classification.

Figure 5-15.
Selected teaching and research indicators for full-time doctoral S&E faculty whose primary activity is research: 1993



See appendix table 5-23.

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number of graduate students. The defining feature of this comparison is the lack of contrast. (See figure 5-15.)

The picture that emerges is quite clear. Research faculty also teach. A good many of them teach undergraduates. A division of labor is apparent between the teaching and the research faculty (as defined here), as well as among the latter. Finally, these patterns are not significantly conditioned by the type of academic institution. Almost all research faculty, regardless of institution type, taught some courses in the fall semester of 1992, with about one-third of them teaching undergraduate courses, but the majority primarily taught graduate-level courses. In fact, in the aggregate, the research faculty taught about as many graduate students as the (numerically larger) teaching faculty. In contrast, of all undergraduate semester hours taught, the teaching faculty accounted for 80 percent.

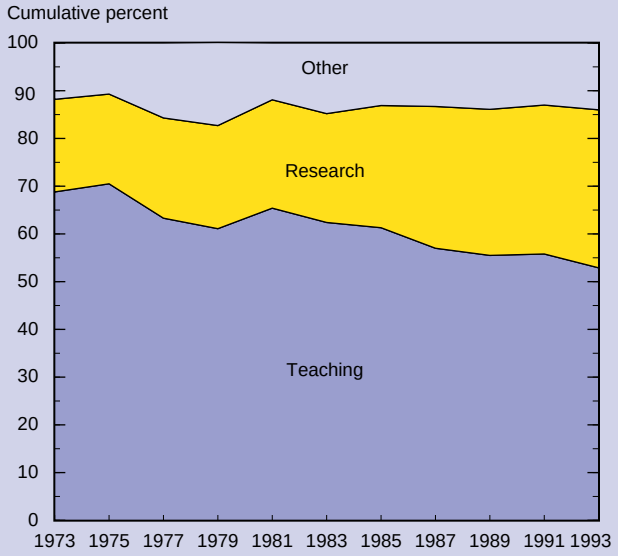
Primary Work Responsibility

This analysis can be supplemented by an examination of a shift in reported academic work responsibilities over the past 2 decades. Full-time doctoral academic S&E faculty are broken down by reported primary work responsibility: teaching, research, and all other types of function. (See figure 5-16 and appendix table 5-24).[39] A long-term composition shift is evident. While the number of those reporting teaching as their primary responsibility remained relatively constant during the 1980s, those choosing research continued to increase. The resulting relative growth in the research function (from 19 percent in 1973 to 33 percent in 1993) contrasts with a relative decline in the proportion—but not the number—of those reporting primary responsibility for teaching (from 69 to 53 percent). The fraction of those with "other" primary work responsibilities (including research management) has fluctuated between 12 and 17 percent, with no clear trend evident.

These trends have to be set in context. Through 1989, both faculty and nonfaculty employment of doctoral scientists and engineers expanded; then faculty employment leveled off. (See appendix table 5-20.) Total enrollment in S&E for selected years and S&E degrees are compared (see text table 5-7), as are the number of doctoral scientists and engineers reporting teaching as their primary responsibility ("teachers;" others are not shown in the table). It is evident that the number of teachers (as defined), while fluctuating, has increased very little since 1981; enrollment may have declined somewhat, but degree production has not declined. In fact, the rough ratios of degrees to teachers (as defined) and enrollment to teachers shown in the table, have been quite stable. These figures suggest that the teaching function has not suffered, even as academic institutions proceeded to employ more

[39] *Based on full-time faculty only,* defined as full, associate, and assistant professors, and instructors. Responsibility for research includes development and design, but excludes management of R&D. This information was not available in 1993 and was included with "other" for all years. Postdoctorates, research associates, and other full-time nonfaculty appointments are excluded. Data are derived from SDR.

Figure 5-16.
Distribution of full-time S&E academic doctoral faculty, by primary work responsibility



S&E = science and engineering

See appendix table 5-24.

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S&E doctorates who viewed research as their primary work responsibility.

In fact, half or more of all full-time faculty with research as their primary responsibility spend the next largest portion of their time teaching. (See figure 5-17.)[40] Only a small fraction of full-time faculty report research as their primary and secondary endeavors (e.g., reporting basic research as their primary and applied research as their secondary work responsibility).

The employment shifts described here have affected all fields.[41] The shifts are especially prominent in the life sciences, which have received about 55 percent of all academic R&D funds through the years. Just over one-third—36 percent in 1993—of full-time doctoral faculty in these fields reported teaching as their primary responsibility, compared with 54 percent 2 decades earlier. In contrast, the fraction identifying research as their primary responsibility increased from 32 percent to 48 percent over the period, the highest in any field. Similar trends can be observed in the physical and environmental sciences. (See appendix table 5-24.)

[40]These figures are derived from the 1993 SDR, which does not provide further information on this point, but see the discussion in succeeding paragraphs.

[41]Data for the computer sciences are ambiguous, as a result of the small numbers involved. As a relatively new field, it may behave somewhat differently from the more established ones, but it is unlikely to be sheltered entirely from these pervasive developments.

Text table 5-7.
Enrollment, degree production, and S&E doctoral faculty with primary responsibility for teaching

	Degrees in S&E	S&E doctoral facility who say teaching is primary duty	Enrollment in S&E	Degrees/ teachers	Enrollment/ teachers
	Number			Ratio	
1973	424,288	73,171	–	6	–
1975	434,639	83,782	–	5	–
1976	439,622	–	1,184,000	–	14
1977	440,514	82,056	–	5	–
1978	442,869	–	1,231,000	–	15
1979	443,248	83,433	–	5	–
1980	446,450	–	1,326,000	–	15
1981	450,621	95,388	–	5	–
1983	460,173	97,123	–	5	–
1984	467,510	–	1,103,000	–	11
1985	477,404	100,485	–	5	–
1986	483,345	–	1,030,000	–	10
1987	479,273	98,530	–	5	–
1988	469,826	–	976,000	–	10
1989	471,858	99,941	–	5	–
1991	490,341	102,557	–	5	–
1993	538,883	97,729	–	6	–

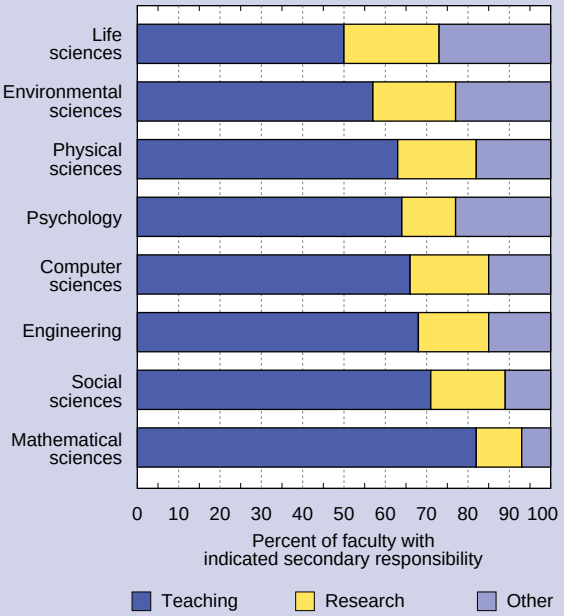
– = Not provided

NOTES: Degrees are bachelor's plus master's. Enrollment is total enrollment as reported to U.S. Department of Education. The number of teachers is derived from SDR respondents who described teaching as their primary responsibility.

SOURCE: National Science Foundation, *CASPAR* data base, special tabulations.

Science & Engineering Indicators – 1996

Figure 5-17.
Distribution of secondary work responsibility of S&E full-time doctoral faculty whose primary responsibility is research: 1993



S&E = science and engineering

See appendix table 5-24.

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Women in Academic Research and Development[42]

The overall academic employment of women with Ph.D.s in S&E more than doubled from 1979 to 1993, jumping from 19,200 to 46,500. Over the same period, the number of women active in R&D tripled, increasing from 10,200 to 30,500. (See appendix table 5-19.) Because of this high growth rate, women made up 20 percent of all academic researchers in 1993, compared with 11 percent in 1979. (See appendix table 5-25.)

The rise in the proportion of women researchers was roughly in line with the increase in women's share of academic employment. In 1993, women constituted 22 percent of all academic doctoral scientists and engineers. This share varied by field, from a high of 41 percent in psychology and 28 percent in the life sciences, to less than 5 percent in engineering (but up from 1 percent in 1979). The physical and environmental sciences and mathematics also had relatively low percentages (between 10 and 11 percent).

In 1993, 40 percent of all women were employed in the life sciences, as were 44 percent of all female researchers. (See appendix table 5-19.) Relatively large proportions of women, compared with men, were also found in the social sciences and psychology. These three areas accounted for 85 percent of all women researchers in 1993, compared with 58 percent of all men.

Minorities in Academic Research and Development[43]

The absolute number of minority researchers in academia remains low for all groups except Asians. In 1993, there were approximately 2,900 blacks; 3,600 Hispanics; and perhaps 700 Native Americans in academia. (See appendix table 5-26.) This compares with 1979, when the combined number of underrepresented minorities was 2,500. Growth among researchers during the period went hand in hand with growth in academic employment: from 1,950 to 4,800 for blacks; 2,300 to 5,000 for Hispanics; and 600 to 1,000 for Native Americans. The increases in these employment numbers are quite consistent with the number of minority Ph.D.s produced since the late 1970s.

Over the period, the relative employment gains (and associated growth in researchers) have been greater for underrepresented minorities than for majority doctorate holders. Employment of underrepresented minorities doubled (from the very low base noted earlier) from 1979 to 1993, and the number of researchers from underrepresented groups tripled. Gains for specific fields varied, with the physical, environmental, and life sciences broadly ranging around the S&E total, and with mathematics, the computer sciences, psychology, and engineering exceeding it. (See appendix table 5-26.)

As a result, underrepresented minorities in 1993 comprised about 5 percent each of total employment and academic researchers, with the social and computer sciences slightly above (about 7 percent) and the environmental sciences and engineering lower than this average.

Asian doctorate holders made substantial gains in academic employment and among doctoral researchers. Employment rose from 9,800 in 1979 to 21,000 in 1993, while the number of researchers rose from 7,000 to 17,600. Asians now comprise 10 percent of academic S&E employment and 12 percent of all doctoral researchers. They are heavily represented in the field of computer sciences (which accounts for 30 percent of total Asian academic employment and 36 percent of all Asian researchers) and engineering (which accounts for 20 and 24 percent, respectively). In every field but the environmental and social sciences, a greater proportion of Asian doctorate holders is active in research than any other group, exceeding them by at least 10 percentage points. (See appendix tables 5-25 and 5-26.)

Federal Government Support of Academic Researchers

The extent of Federal Government support to academic researchers is of perennial interest. In 1993, 38 percent of the academic doctoral scientists and engineers

[42] The discussion herein is succinct and focused because a report, providing for more complete coverage, has just been published. See SRS (1994d).

[43] See SRS (1994d) for a more detailed discussion.

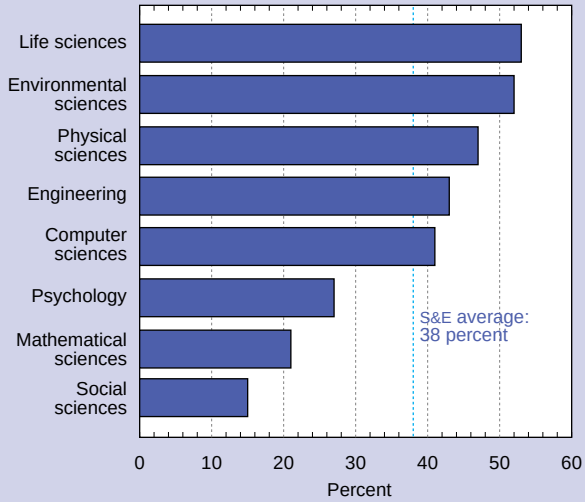
responding to SDR reported receiving funding from the Government during the week of April 15. (See appendix table 5-27.) This number cannot easily be compared with those from earlier years (50 percent in 1989 and 51 percent in 1991), which were based on a year-long reference period.[44]

The U.S. Department of Education's 1993 faculty survey (NSPF) also asked about Federal Government support. The NSPF estimate of the number of doctoral scientists and engineers in academia and its estimate of the number of researchers agree very well with those derived from SDR. Fifty-one percent of NSPF's science and engineering doctorate holders reported having Federal Government funding in the fall semester of academic year 1993, in line with earlier SDR estimates based on year-long reference periods. This estimate, when taken together with information presented earlier regarding the growth in Federal funding, suggests that no major changes have occurred in the number or proportion of researchers supported with Federal funds. This tentative conclusion is further bolstered by the lack of fluctuation in the number of federally funded research assistants in 1993, relative to earlier years.

Notable field differences exist in the proportion of researchers with Federal support.[45] The proportions for the life, environmental, and physical sciences and engineering lie above the S&E average. Those for mathematics, psychology, and the social sciences fall clearly below the mean. (See figure 5-18.)

It has been observed anecdotally in recent years that obtaining Federal support is becoming more difficult. Some evidence from SDR has indirect bearing on this assertion. A growing fraction of academics with Federal Government support have to obtain it from more than a single agency. (See appendix table 5-28.) This trend can be observed in most fields. Those with the highest levels of multi-agency support are the environmental and computer sciences (at above 40 percent) and engineering and the physical sciences (at above 30 percent). Single-agency support is most prominent in the life and social sciences, psychology, and mathematics.

Figure 5-18.
Percent of academic doctoral scientists and engineers reporting Federal Government support, by field: 1993



S&E = science and engineering

See appendix table 5-27.

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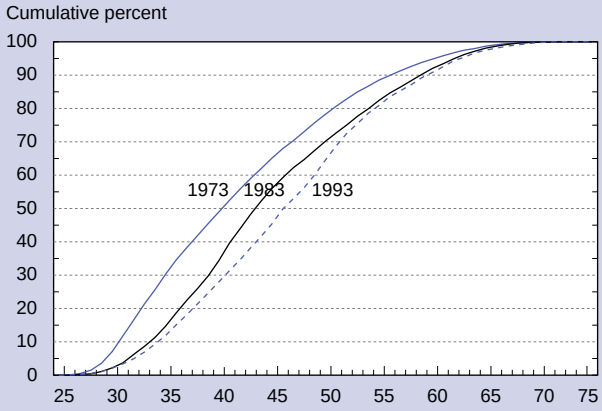
The Changing Age Structure of the Academic Faculty

The rapid pace of hiring into academic faculty positions, created during the 1960s and into the early 1970s to accommodate soaring enrollments, resulted in a peculiar phenomenon: an aging professoriate. (See figure 5-19.) The proportion of all full-time faculty in a given year and at a given age category shows their progressive aging. (See appendix table 5-29.) A noteworthy feature of these data involves the upper tail of these age distribu-

Figure 5-19.
Cumulative age distribution of full-time doctoral science and engineering faculty



See appendix table 5-29.

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[44]Indirect evidence that the extent of support is understated can be gleaned from the number of senior scientists and postdoctorates supported by NSF grants. This number is published annually as part of NSF's budget submission. It bears a relatively stable relationship to numbers derived from SDR in 1987, 1989, and 1991, but diverges sharply from those in 1993. (The figures are never identical, however, since NSF's numbers reflect those funded in a given fiscal year, while SDR's numbers reflect those with support from NSF, regardless of when it was awarded.)

[45]The relative field shares of federally supported researchers appear to be stable across recent survey years (i.e., they are relatively unaffected by changes in the survey). The distribution (but not the magnitudes) based on NSPF estimates is quite similar.

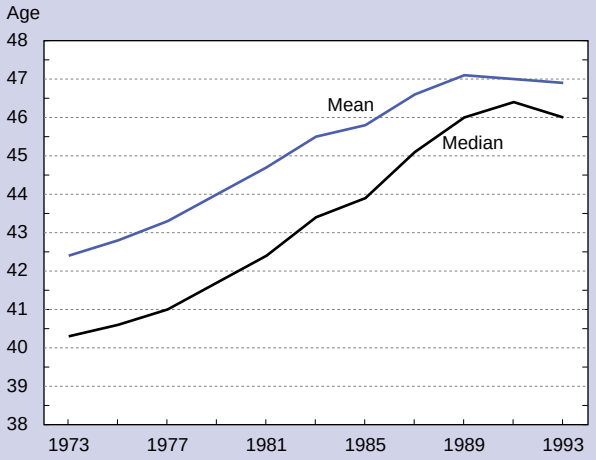
tions. The fraction of the total faculty encountered beyond age 65 is less than 2 percent (i.e., academics tend to retire at or before that age).[46]

The median and mean ages of doctoral faculty show a clear trend: a notable change after 1989, with a flattening of a long upward trend. (See figure 5-20.) The result of this change on the age structure of full-time faculty can now be interpreted in light of the number of full-time S&E faculty, which had consistently grown since the early 1970s through 1989, but has changed little since then. (See figure 5-21.) During the years of gradual growth, the average faculty age climbed from 42 to 47 years, then leveled off. The age distribution of full-time faculty throughout the past 2 decades clearly shows that very few remain in active full-time faculty appointments past the age of 65.[47] Thus, these data suggest that for the system as a whole, though not necessarily for any given department or institution, a rough balance has been maintained between attrition from all causes and hiring. However, the gradual replacement hiring suggested by the data from 1989 onward contrasts with the preceding decade and a half, when hiring into full-time faculty positions increased at a fairly steady rate, and when smaller numbers of doctorates were awarded than in recent years.

[46]These data are based on SDR. One change in 1991 was to exclude anyone older than age 75 from the sample. The data here have been adjusted for all years to take account of this change. In any case, there never were more than a tiny number of persons fully employed in faculty positions at or beyond that age.

[47]A recent NAS study of the likely effects of changes that eliminated the enforcement of age-related retirement provisions concluded that faculty at the major research universities would likely remain active well beyond the normal retirement age. It is too soon to offer solid evidence on this issue, except to note the 1993 age distribution of faculty in the Carnegie research institutions did not differ greatly from the national average. The present discussion merely establishes that, for the system as a whole, most academics have retired from full-time professional employment by the time they have reached age 65.

Figure 5-20.
Average age of full-time doctoral science and engineering faculty



See appendix table 5-29.

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Article Outputs from Scientific Research

This section deals with the published outputs of natural science and engineering research, specifically, articles published in refereed journals. It places the United States in the context of other countries contributing to the world scientific literature and examines that literature by field. The discussion is organized around four broad foci that involve an examination of: (1) the sheer output volume of research (by country and field and, in the case of the United States, by sector), using article counts as the indicator; (2) collaboration in the conduct of research (cross-sectoral and international totals) using multiauthor articles as the indicator; (3) the use of research outputs in further scientific activities (interdisciplinary, intersectoral, and international), using citation patterns as the indicator;[48] and (4) citations on patent applications to this literature, as an indicator of its presumed practical utility.

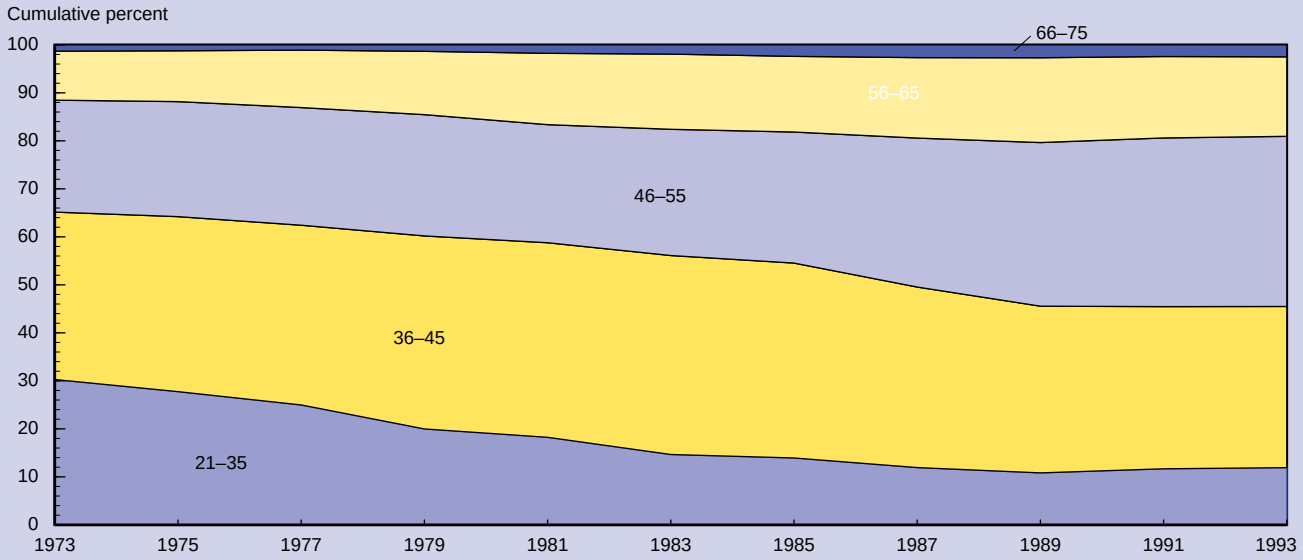
The data base consists of scientific and engineering articles published in the set of 4,681 natural science and engineering journals covered by the Institute of Scientific Information's (ISI) Science Citation Index (SCI). SCI covers major refereed scientific and technical (S&T) journals from around the world.[49] It classifies journals, and the articles appearing in them, into 99 subfields under 8 broad fields (see appendix table 5-30):

- Biological sciences (751 journals),
- Biomedical sciences (636 journals),
- Clinical medicine (1,425 journals),
- Chemistry (422 journals),
- Physics (307 journals),
- Earth and space sciences (283 journals),
- Mathematics (169 journals), and
- Engineering technologies (688 journals).

[48]Other uses of publication and citation data have included the delineation and development of scientific specialties, connections among disciplines, and attempts at characterizing scientific quality or the relative scientific merit of countries, regions, institutions, departments, research teams, and investigators. Some of these applications are controversial; none of them is undertaken here.

[49]The data base encompasses the natural sciences and engineering. The social and behavioral sciences tend to rely more on publications vehicles not covered by ISI (e.g., books and monographs). For this reason, these fields are omitted from the present discussion. The data base also excludes letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments. ISI periodically updates its journals coverage, based in part on references in covered publications to others not yet included. Given this citations-based updating, one can conclude that ISI provides reasonably good coverage of a core set of scientific journals (albeit with some English language bias), but not necessarily of all that may be of local or regional importance. The last point may be particularly salient for the engineering technologies category and for nations with a small science base.

Figure 5-21.
Age distribution of full-time academic doctoral science and engineering faculty



Number of full-time faculty

1973	1975	1977	1979	1981	1983	1985	1987	1989	1991	1993
103,099	116,291	125,459	130,722	141,476	147,762	156,335	163,767	168,811	172,143	171,818

See appendix table 5-29.

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Article Outputs, by Country

The article counts reported here indicate the sheer volume of scientific publishing in a given field and country, as reflected in this set of core journals. These counts cannot be interpreted in a straightforward fashion as comparative indicators of scientific productivity (e.g., for field-to-field or country-to-country comparisons) or of scientific quality. They reflect the size of scientific fields, their differing publishing conventions, and, probably, national differences in scientific publishing practices as well. Thus, the focus of this section is on broad trends and relationships.

In 1993, SCI recorded a world total of 414,000 science and engineering articles. As in previous years, in 1993, the United States contributed the largest fraction (34 percent), by far, of all articles. (See appendix table 5-31.) Other major article-producing countries were Japan (9 percent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent). (The former Soviet Union contributed about 5 percent of the total.) No other country's production exceeded 5 percent. (See appendix table 5-32.) The broader regional distribution of these articles includes North America (38 percent); Western, Northern, and Southern European countries (34 percent); the former Soviet Bloc countries (8 percent); and Asia (14 percent). (See figure 5-22.)

The number of scientific articles worldwide (in this set of journals) grew at an average rate of roughly 1 percent per year,[50] from about 369,000 in 1981 to 418,000 in 1993. As one would expect, given these large numbers, the overall distribution among countries has generally not changed dramatically, with some exceptions.

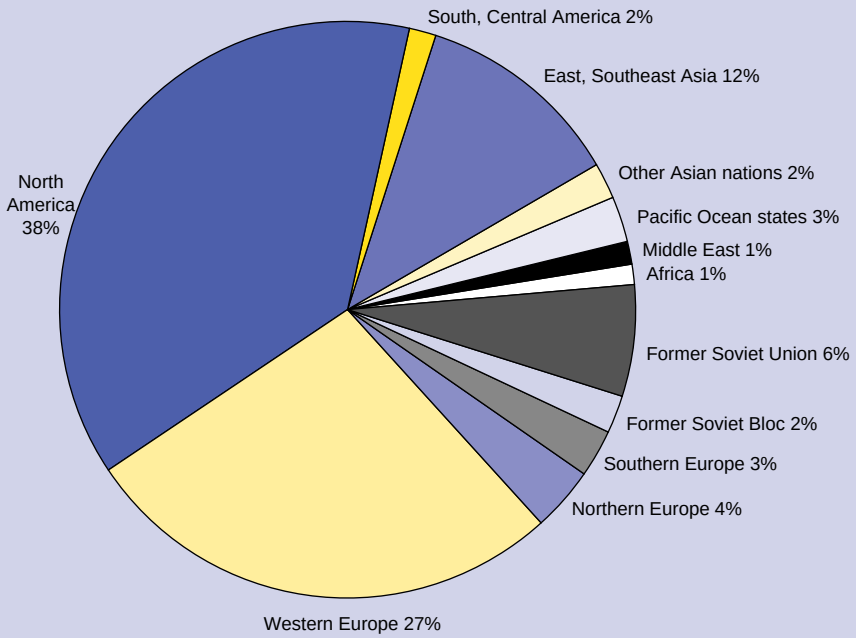
The number of U.S. publications rose from about 132,000 in 1981 to 141,000 in 1993, but the U.S. share of world articles declined moderately, from 36 percent in 1981 to 34 percent in 1993, reflecting relatively more rapid growth in the publications output of many other nations. (See appendix table 5-32.)

Some countries' publications output actually declined. The number of articles from countries of the former Soviet Union, as well as from former members of the Soviet Bloc, fell over the period, leading to a decline in their world share from 11 to 7 percent. India had a notable drop off in article output, falling by 28 percent between 1981 and 1993. Consequently, its world share declined from 3 to 2 percent.

One can only speculate about the reasons behind these declines. In the case of the former Soviet Bloc nations, it

[50]Recent unpublished work by Zvi Griliches and James Adams, based on ISI's expanding journals set, suggests that the "real" growth rate may be higher. However, it is unclear to what extent this higher rate reflects expanded coverage by ISI, as opposed to a real expansion in scientific article production.

Figure 5-22.
Distribution of articles in world scientific journals, by region: 1993



See appendix table 5-32.

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would be a mistake to conclude that the collapse of this alliance led to the observed decline in published output. Articles reflect work done one or more years earlier, and the observed decline in publishing was gradual and covered the entire period. It is more likely that relative political and scientific isolation, combined with economic difficulties, affected the conduct of scientific research. India has a sizable science and engineering base, thus, the drop in its article output, from 11,700 to 8,000, presents a genuine puzzle. (See Chapter 2, Higher Education in Science and Engineering.) Does this observed decline accurately reflect the country's current article output volume? Or, conversely, does it represent a shift toward domestic publication vehicles serving an increasingly mature scientific and engineering infrastructure?

Southeast Asia's emergence as a potent, high-technology economic region has been noted.[51] The region is also growing increasingly prominent in world article output, indicating an expansion of its indigenous basic science base. In little more than a decade, its world article share rose from about 7.5 to 12 percent. (See appendix table 5-32.) The article volume of the newly industrialized economies (NIEs)—South Korea, Hong Kong, Taiwan, and Singapore—grew from about 1,000 in the early 1980s to more than 6,000 in 1993, with continuing strong growth.[52] The growth in China's volume of articles (from 1,100 in 1981 to 5,000 in 1993) is equally impressive. In terms of world share, this growth roughly represents a rise, over the period, from 0.3 percent to 1.5 percent of the total each for the combined NIEs and for China. In addition, Japan expanded its already strong article output from 25,100 in 1981 to 36,700 in 1993 and raised its world share from 7.0 to 9.5 percent, making it the second-largest contributor to this article data base. Other countries in the region produced fewer articles and had more modest, but still robust, growth rates.

Western Europe experienced a modest increase in its world share, largely as a result of the strong growth in the number of publications in its southern-tier countries. For the major Western European countries, the general pattern was one of modest growth (increasing by no more than 20 percent) from 1981 to 1993 (i.e., generally in line with overall growth patterns. Growth rates for Italy, the Netherlands, Norway, and Greece were stronger, ranging from 30 to 75 percent. Article output

[51]The emergence of these Asian countries in high-tech economic activity is described in SRS (1995c). The expansion of their education activities in science, engineering, and technology are described in SRS (1993).

[52]This is a rough estimate because Hong Kong's articles before 1987 were included in China's total. The estimate assumes that Hong Kong's growth rate in the early 1980s was lower than that of the other NIEs (i.e., this is a conservative estimate).

rose by over 200 percent in Spain and Portugal; this is very likely the result of these countries' stronger economic and political integration into the European community and their increased investment in R&D.

Distribution of Articles, by Field

The life sciences accounted for the bulk (56 percent in 1993) of articles in the SCI data base. (See appendix table 5-31.) In the broad field breakdown of these articles, the single largest category, clinical medicine, contributed 31 percent of all publications; biomedical research, 17 percent; and the biological sciences, another 8 percent. (See figure 5-23.) The physical, earth, and space sciences accounted for 35 percent of the total: 16 percent for physics, 14 percent for chemistry, and 5 percent for earth and space sciences (which, in this data base, include environmental sciences and astronomy). Seven percent of the articles were classified as engineering and technology and 2 percent as mathematics and statistics.

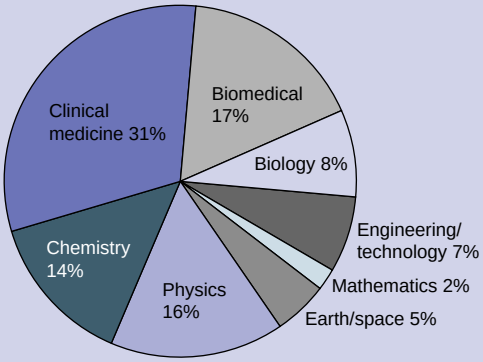
The field distribution of these articles has shifted somewhat since the early 1980s, but the changes have been gradual, because of the large number of articles published each year. (See appendix table 5-31.) Within the life sciences, the biological sciences lost some of its share while biomedical research gained, suggesting a gradual shift in research focus. Biological sciences articles, which accounted for 10.7 percent of the total in 1981, declined to 8.1 percent in 1993, while biomedical research articles increased from 15.0 to 16.7 percent of the total. Physics articles also gained in share, rising from 12.4 percent to 15.4 percent of the total over the period. Mathematics, chemistry, and engineering and technology had offsetting marginal losses in share.

The United States in the International Context

In 1993, 141,000 U.S. articles (up from 132,000 in 1981) were published in the world's influential S&T journals. (See appendix table 5-31.) This accounted for 34 percent of the world publications volume in 1993. The U.S. share of world publications, by broad field, indicates that U.S. contributions in chemistry and physics were well below the average. (See figure 5-24.) The 13,300 U.S. chemistry articles in 1993 accounted for 23 percent of the world's total; the 16,900 physics articles accounted for 27 percent. Fields in which the U.S. share exceeded the U.S. average were the earth and space sciences (41 percent), clinical medicine and biomedical research (39 percent), and mathematics (39 percent).

The U.S. share of the world's S&E articles has been declining gradually but steadily. (See appendix table 5-31.) This downward trend, already evident in the early 1970s, reflects the continuing expansion of S&E research activities of countries around the globe. This overall trend obscures field differences. In physics (a field which gained in world share between 1981 and 1993), the volume of U.S. publications grew by about 30 percent over the period, but the U.S. share declined because of even stronger growth in the volume of publications by other nations. The U.S. share in engineering and technology fields dropped by 6 percentage points, from 41 to 35 percent, while its shares of articles in the biological sciences, clinical medicine, and in the earth and space sciences declined more gradually. U.S. chemistry publications, on the other hand, rose gradually from 20 to 23 percent of the world's total.

Figure 5-23.
Distribution of articles in world scientific journals, by field: 1993



See appendix table 5-32.

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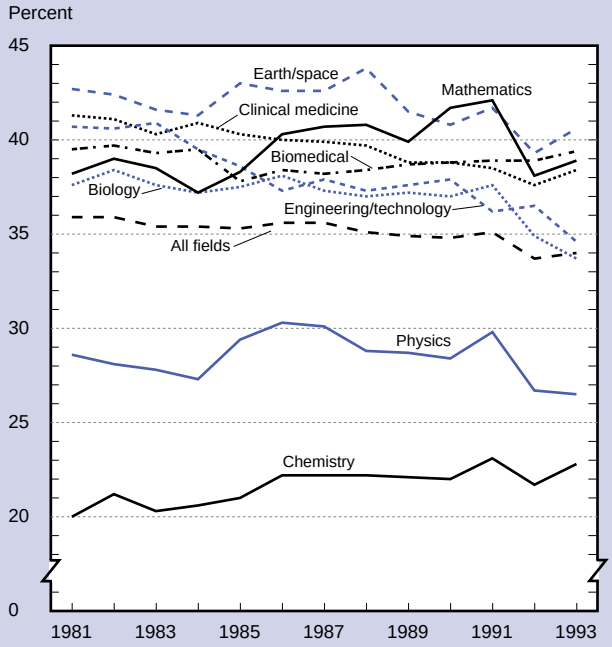
Figure 5-24.
U.S. share of world scientific articles, by field



See appendix table 5-31.

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Differences in Field Distribution Among Nations

The results of nations' implicit and explicit policy choices about the distribution of their support for science across S&E fields are reflected in the data at hand. (Compare with appendix table 5-33.) They show that nations have very different patterns of scientific activity and that these patterns change over time.

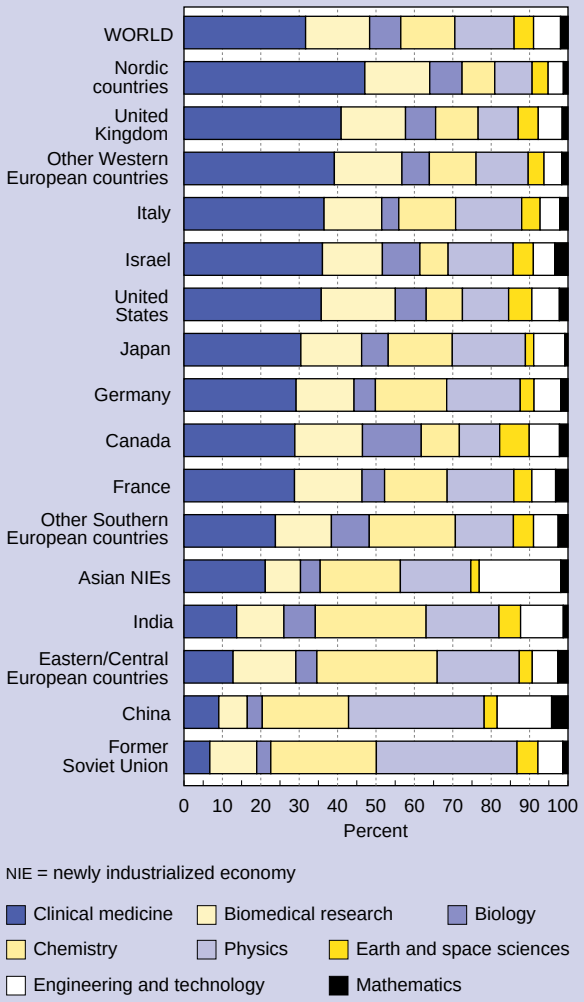
Very different mixes of articles are evident for selected countries. (See figure 5-25.) The U.S. pattern shows relatively greater emphasis than the world average on clinical medicine, biomedical research, and the earth and space sciences, and relatively lower emphasis on chemistry and physics. Germany, France, and Italy have roughly similar patterns: relatively more emphasis on chemistry, and especially physics, and less emphasis on the medical and life sciences.[53] This same pattern is evident for Asian countries, but in heightened form: much lower emphasis on the life and medical sciences, considerably greater emphasis on the physical sciences, and a strong emphasis on the engineering and technology fields. Publishing patterns in the former Soviet Union and its former Eastern European allies show a heavy emphasis on chemistry and physics and a very low emphasis on clinical, biomedical, and biology research, but without the relatively strong proportion of publications in engineering and technology.

Countries shift the focus of their scientific activities over time, usually—but not always—gradually. The 13-year span of publications data reveals the nature of some of these shifts and compares the difference in the 1993 fraction of a country's articles, relative to its 1981 share. (See text table 5-8.) (For ease of understanding, only changes exceeding 1 percentage point are shown; appendix table 5-33 shows the detailed data.) For the world as a whole, change was gradual: a shift into biomedical research was roughly offset by a decline in biology, and some growth in the physics share was accompanied by modest declines in the chemistry, engineering/technology, and mathematics categories. Trends in the United States, Western Europe, Canada, Australia, and Israel generally have been similar, thus shaping worldwide trends. But publishing in the former Soviet Union and its former allies indicates a different set of choices, as does the field composition of articles in the other Asian nations.

In the former Soviet Union, clinical medicine's share of publications—already low by world standards in the early 1980s—fell further, even as the total number of publications in all fields kept declining; the same occurred in its former allied nations. In both sets of countries, the clinical medicine share fell by 6 percentage points. In contrast, physics gained 11 and 7 percentage points in the former Soviet Union and in the former allied nations, signaling shifts of a magnitude seen only in China, where they occurred from a much lower article base. In all likelihood, these dramatic composition changes reflect a relative degree of support and protection afforded the physical sciences fields as the Eastern European and former Soviet nations adjust to a changed political and economic situation.

The Asian nations' changes are startling, but one must bear in mind both the very high publication growth rates achieved by many of these nations and their often low initial article counts. It appears on the whole that the physical sciences and engineering/technology fields are receiving increasing emphasis, while support for biology is rapidly decreasing, relative to other fields. China, especially, embodies these trends, which appear in more muted form in the NIEs. In the case of Japan, the fairly sizable shift into clinical medicine (a field that previously had not been greatly emphasized) is noteworthy.

Figure 5-25.
Field distribution of articles for selected countries: 1993



See appendix table 5-33.

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[53]Similar patterns have been observed in research funding. See Martin and Irvine (1986).

Text table 5-8.
Changes in selected nations' article field distributions: 1981–93

	Clinical medicine	Biomedical research	Biology	Chemistry	Physics	Earth and space	Engineering	Mathematics
	Field's percentage in 1993 minus percentage in 1981							
United States	–	3.0	–3.0	1.3	2.3	–	–2.2	–
United Kingdom	4.4	1.7	–3.5	–	1.1	–	–2.2	–
Germany	–1.0	–	–3.2	1.7	6.4	–	–1.6	–2.3
France	–3.6	2.3	–1.4	–	3.2	–	–	–
Italy	2.1	1.0	–1.3	–3.8	2.7	–	–	–
Other Southern Europe	–	–2.8	1.5	–1.0	1.7	1.9	–	–
Nordic countries	–4.4	1.1	–	–	2.7	1.6	–	–
Other Western Europe	1.3	2.6	–	–1.3	–	1.0	–1.6	–
Japan	7.2	2.3	–2.6	–6.8	4.3	–	–3.1	–1.0
Canada	1.5	2.2	–1.5	–1.5	1.4	1.6	–1.1	–1.4
Former Soviet Union	–6.0	1.7	–	–2.9	11.2	–	–1.4	–1.3
Eastern and Central Europe	–6.2	1.0	–4.0	1.8	7.1	1.2	–	–
Israel	1.8	–	–2.0	–1.9	3.5	1.9	–2.3	–
Other Middle Eastern	6.5	–2.3	–3.6	–1.1	–	–	3.7	–3.1
Africa	–3.3	1.3	–1.4	2.3	2.6	1.7	–1.4	–
Central and South America	–5.3	–1.2	–	–	6.2	–	–	–
Australia and New Zealand	3.4	2.5	–2.6	–1.7	1.1	–	–1.1	–
India	1.0	–1.3	–8.2	2.0	4.6	1.6	3.1	–1.7
China	–5.2	3.0	–12.3	14.6	13.8	–18.4	4.0	1.5
Asian NIEs	2.3	1.3	–7.0	–	4.6	–	4.5	–4.5
Other Asia	6.5	–1.1	–8.4	6.2	–	1.6	-2.4	–1.6

– = change is less than 1 percent; NIE = newly industrialized economy

NOTE: See appendix table 5-32.

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The preceding discussion has focused on the composition differences in the individual nations' science portfolios. Of course, many commonalities exist along with these differences, and governmental, intergovernmental, and private mechanisms exist to help nations gauge their science policies and activities in the context of their neighbors', partners', and competitors' actions. At the working level, science itself has a strong international perspective, to which we now turn.

International Scientific Collaboration

In many fields, cutting-edge science is increasingly dependent on knowledge, perspectives, and techniques that cross traditional disciplinary boundaries. Often, the scope of the problem (human genome mapping or global environmental trends), combined with complexity and cost, suggest or even dictate broad collaboration that increasingly involves international partners.[54] Both trends—increased collaboration and growing international cooperation—can clearly be seen in the publications data. A pervasive trend in scientific publishing toward greater scientific collaboration affects all fields and all nations, and a steadily growing fraction of most countries' papers involve international coauthorship. This section examines these trends, the U.S. position in international collaboration, who collaborates with whom, how developing and developed nations compare, and what collaboration patterns exist for and among Asian nations.

The indicator used here is the incidence of article coauthorship, in which the authors' institutional affiliations are located in two or more countries. This choice, as dictated by the data base, has some unwelcome consequences. A paper written by a U.S. citizen temporarily residing in the United Kingdom in collaboration with someone at his U.S. home institution is counted as internationally coauthored, thus overstating (in one sense) the extent of such collaboration. On the other hand, a paper coauthored by a British citizen located in the United States and collaborating with someone at the host institution would not be considered internationally coauthored, thus understating the count. Further, the data presented here do not permit the examination of collaboration involving three or more countries. However, the trends evident in the data are sufficiently robust to give confidence that they do not merely reflect flaws in the measure used.

Trends in International Scientific Collaboration

A pronounced worldwide tendency exists toward greater scientific collaboration, as evidenced by patterns of coauthorship of scientific and engineering journal articles. This trend has been accompanied by a marked

[54]See, for example, Office of Technology Assessment (1995) and President's Council of Advisors on Science and Technology (1992). See also Chapter 4, Research and Development: Financial Resources and Institutional Linkages.

increase in collaboration across national boundaries.[55] (See appendix table 5-34.) Put briefly, in 1993, roughly half of all journal articles worldwide had more than one author, and roughly one-quarter of these involved international coauthorship. The number of coauthored articles increased from 121,200 in 1981 (33 percent of the total) to 195,500 in 1993 (47 percent). The number of internationally coauthored articles worldwide increased by 150 percent, from 21,000 to 52,500. The total number of articles also increased, but only by roughly 20 percent. Consequently, the proportion of all articles published worldwide involving some international coauthorship doubled, from 6 percent in 1981 to 13 percent in 1993.

The overall rate of multiple-investigator research, as indicated by coauthorship, ranged from 35 to 58 percent in 1981 and increased by roughly 10 percentage points by 1993. In both cases, India and the former Soviet Union were clear outliers, with collaboration rates of about half of the world's lower ranking countries.

The United States contributes to approximately half of the world's internationally coauthored papers; this figure is well in excess of its 34-percent share of world article output. It is among the countries with the highest percentage of coauthorship (53 percent), but it ranks in the low end in terms of the overall percentage of articles involving international collaboration (14 percent for 1988–93 and 16 percent in 1993). This occurs solely as a result of its very large publications base. (See appendix table 5-35.) Patterns of coauthorship among countries, as discussed below, illustrate the special role of the U.S. scientific enterprise in world science.

The positive trend in the growth of the number of collaboratively authored papers in the United States roughly parallels the trend in other countries. While the overall number of U.S. articles increased by 6 percent between 1981 and 1993, the number of internationally coauthored papers (i.e., those with at least one author at a U.S. institution and at least one abroad) rose by 140 percent, from 10,292 in 1981 to 24,737 in 1993. As a share of all U.S. publications, these articles increased from 7 to 16 percent over the period.

The role of the United States in international collaboration (as measured by coauthorship) is characterized by two complementary trends. For almost every nation with substantial international coauthorship, the total number of its articles with one or more U.S. collaborators rose strongly between 1981 and 1993. For example, in the early 1980s, about 4 to 7 percent of articles published by major European industrial nations involved collaboration with U.S.-based authors. This fraction had risen to 8 to 12 percent by the early 1990s. This increase suggests the substantial influence of U.S. science in European scientific research. Corresponding numbers for Canada were 9 percent in 1981 and 15 percent in 1993. For Japan, which collaborates little, the numbers were 3 percent in 1981 and 6 percent in 1993.

Throughout this period, many of these nations increased their collaborative ties, not just with the United States, but also with nations around the world. Thus, among all internationally coauthored articles, the U.S. share gradually diminished in many nations.

Who Collaborates with Whom?

Scientific collaboration, as measured by international coauthorship, centers to a remarkable degree on the United States. (See appendix table 5-35.) Roughly 20 to 25 percent of all internationally coauthored papers from European countries involve U.S. authors. The same is true for African and many Asian publications. Elsewhere, U.S. scientists have been even more actively involved. Between 1988 and 1993, U.S. authors collaborated in 30 to 35 percent of the internationally coauthored publications of India, Australia, and China; in 45 percent of those from Israel and Japan; and in fully half of those from the Asian NIEs. For scientists in the former Soviet Union and its Eastern European allies, U.S. scientists tended to account for only about 15 percent of their international coauthorships; scientists in these countries were more closely tied to Western European, and each other's, science establishments.

The U.S. pattern of international coauthorship stands in sharp contrast to those just described (as it must, given the high percentages of U.S. involvement in most other nations' international collaborative works). No single country's authors exceed 12 percent of the United States' internationally coauthored papers. The United Kingdom, Canada, and Germany each have a 10- to 12-percent share, and most other individual nations fall well below this level.

Countries with small indigenous science establishments tend to have higher levels of international coauthorship (i.e., as a percentage of their total article output) than those with larger, more mature systems. Rather than collaborating regionally, scientists from developing nations tend to work with those from major science-producing nations. One can conclude that the viability of the local science infrastructure depends, to a fair extent, on these international lines of contact. In the case of mature, small nations (e.g., the Nordic or smaller Western European countries), this pattern is augmented by regional collaboration. Political isolation (as in the case of Eastern Europe and the countries of the former Soviet Union) and cultural or language barriers (as in the case of Japan) can influence these patterns and result in unusually low degrees of international collaboration.

The Asian nations, with their rapidly expanding scientific output and high levels of international collaboration, also collaborate regionally. Ten to 20 percent of their international coauthorship activity involves scientists from other Asian nations, more than half of whom are from Japan.

[55]Among the causes of these increases are no doubt the extent of advanced training students receive outside their native countries and the web of intergovernmental agreements inviting or requiring multinational participation in research activities.

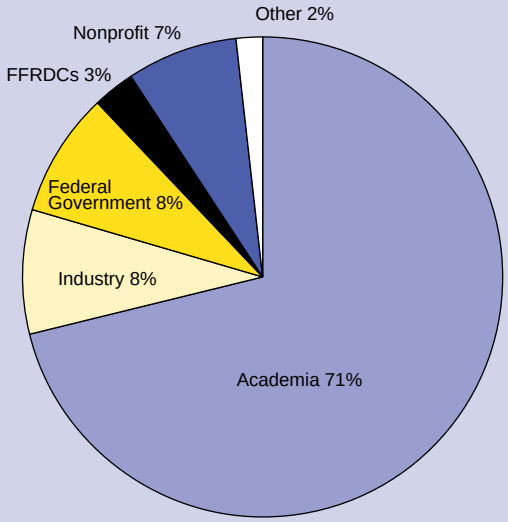
Sectoral Distribution of U.S. Scientific and Technical Articles

In the United States, increasing attention has been given to cross-sectoral collaboration in scientific and engineering research. The collaboration between universities and industry has been of particular interest, both for enriching research approaches and perspectives and for efficiently channeling research results toward practical use. This section discusses the sectoral distribution of U.S. articles and the patterns of cross-sectoral collaboration.

The bulk (71 percent in 1993) of U.S. articles in the natural sciences and engineering is published by academic researchers. (See appendix table 5-36 and figure 5-26.) Industry and the Federal Government contributed 8 percent each; nonprofit institutions (mainly health-related organizations publishing in the biological and medical fields), 7 percent; FFRDCs (publishing mainly in the physical sciences and in engineering), 3 percent; and all other organizations, including state governments, 2 percent.

Since 1981, there has been a very gradual shift in the sectoral distribution of U.S. articles: Academia's share has grown from 68 to 71 percent; industry and nonprofit institutions have maintained their relative positions; and the Federal Government, FFRDCs, and other types of organization all experienced small losses in their shares. In fact, the number of Federal Government and FFRDC articles actually declined in several fields—engineering and technology, mathematics, clinical medicine, and biology—but not in chemistry, physics, or the earth and space sciences. (See appendix table 5-36.)

Figure 5-26.
Distribution of U.S. scientific and technical articles, by sector: 1993



FFRDC = federally funded research development center

See appendix table 5-36.

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Cross-Sectoral Collaboration in the United States

Increasingly, scientific and engineering research in the United States involves investigators from different employment sectors, as evidenced by a steady increase in the number and proportion of articles with collaborators from multiple sectors. This trend is evident in all sectors. (See appendix table 5-37.)

Just under one quarter (23 percent) of all academic papers[56] in 1993 involved collaboration with authors from one or more other sectors: 8 percent each from the Federal Government and nonprofit institutions, 5 percent from industry, 3 percent from FFRDCs, and 2 percent from other sectors including state governments. The nonacademic sectors had much higher levels of

Text table 5-9.
Change in number of cross-sectoral articles, by sector

	All articles	Cross-sectoral	All articles	Cross-sectoral
	Number		Percent change	
Academia				
1981 . . .	104,112	21,192	–	–
1993 . . .	121,869	28,167	17.1	32.9
Industry				
1981 . . .	13,462	3,671	–	–
1993 . . .	17,469	8,202	29.8	123.4
Federal				
1981 . . .	18,592	9,178	–	–
1993 . . .	19,283	11,190	3.7	21.9
FFRDCs				
1981 . . .	6,393	2,473	–	–
1993 . . .	6,874	3,948	7.5	59.6
Nonprofit				
1981 . . .	14,624	8,035	–	–
1993 . . .	17,310	10,539	18.4	31.2
Other				
1981 . . .	4,602	2,864	–	–
1993 . . .	4,894	3,591	6.3	25.4

– = not applicable; FFRDC = federally funded research and development center

NOTE: See appendix table 5-36.

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[56]In this section, intersectoral collaboration is determined by the authors' institutional affiliation. An article with one academic and one industrial sector author is counted once (not fractionally) in each category. For example, an article with three academic contributors, from three different institutions, counts as a single-sector article; a similar article that also involves an industrial sector author and an FFRDC author is counted in all three sectors. In this schema, for any given sector, articles produced collaboratively with all other sectors combined will be smaller than the sum of individual intersectoral collaborations because of collaborations across three or more sectors. Note also that the rates of cross-sector collaboration described here are not comparable with the overall collaboration rates discussed earlier, which included intrasector collaborations.

intersectoral collaboration: 47 percent of the industry papers; 58 percent with of Federal government papers; 57 percent of those published by FFRDCs; 61 percent of the nonprofit papers; and 73 percent of those published in the other sectors.

Since 1981, cross-sectoral collaboration has been increasing in every sector. In each instance, the absolute number of papers involving such collaboration has increased more rapidly than the overall number of articles produced in a given sector. (See text table 5-9.) Increases in article production from 1981 to 1993 have ranged from 4 percent for Federal Government employees to 30 percent for industry. Growth rates for articles involving cross-sector collaboration, however, have ranged from 22 percent for the Federal sector to 123 percent for industry.

Among academic articles, cross-sector collaboration rose from 20 to 23 percent between 1981 and 1993. Academic collaboration with industry nearly doubled. Collaboration with FFRDCs and nonprofit institutions increased moderately, and collaboration with the Federal Government and other sectors remained unchanged. Among articles from industry, the Federal sector, FFRDCs, nonprofit institutions, and other sectors, cross-sector collaboration increased strongly across the board. (See appendix table 5-37.)

The interpretation of these trends and proportions must be set in the context of the dominance, in terms of sheer numbers of articles, of the academic sector in U.S. scientific and technical publishing. In 1993, 38 percent of industry articles involved collaboration with academia (up from 22 percent in 1981); half of the Federal sector's articles had academic collaborators, as did nearly half of the FFRDC articles and more than half of those from nonprofit and other sectors. Thus, it is clear that academic authors were involved, as indicated by joint authorships, in well over half of all intersectoral collaborations.

Intersectoral collaboration is highest in the combined biological and medical sciences and lowest in the physical sciences and in mathematics, although in both cases collaboration has increased since 1981. The pattern for engineering and technology is more complex. The total number of articles in this set of fields declined from 1981 to 1993 in all sectors except academia, but, nevertheless, the number of articles involving cross-sector collaboration increased for each sector. As a result, academic papers show no increase in their share of cross-sectoral collaboration (because a growing number of these papers is offset by the equally strong growth in all academic engineering papers), while nonacademic sectors show substantial increases (because their overall production of engineering publications is falling). (See appendix table 5-38.)

Cross-Sectoral Citation Patterns

The overall distribution of references to U.S. scientific and technical articles largely reflects the sectoral distribution of the articles themselves. From 1990 to 1993, academia and industry received 71 and 8 percent, respectively, of the citations. The shares of the Federal Government and nonprofit institutions (at 10 and 9 percent, respectively) were somewhat higher than their shares of article production; those of FFRDCs and other types of organizations (at 2 and 1 percent, respectively) were somewhat lower. (See appendix table 5-39.)

Academic papers receive the bulk of citations in each sector, attesting to the centrality of results from academic research in the scientific and engineering research activities of other sectors. Between 1990 and 1993, academia received roughly half of the citations in industry, Federal Government, and FFRDC articles and 60 percent of those in the other sectors' papers. However, each sector also cited in-sector papers very heavily, no doubt reflecting the differences in the nature, purpose, and focus of research carried out in them.

Text table 5-10.
Distribution of citations across U.S. performer sectors, by field: 1990–93

Field	Academia	Industry	Federal	FFRDC	Nonprofit	Other
	Percent of total citations to sector					
All fields	70.5	7.9	9.7	1.9	8.8	1.2
Clinical medicine	68.3	5.1	11.3	0.2	12.9	2.2
Biomedical research	72.7	6.9	9.4	0.7	9.7	0.7
Biology	79.2	2.8	13.4	0.2	3.2	1.3
Chemistry	78.5	12.8	4.3	2.7	1.3	0.2
Physics	63.1	20.9	5.1	9.3	1.5	0.1
Earth and space sciences	66.1	4.8	14.4	7.8	6.1	0.8
Mathematics	88.8	4.9	2.5	1.8	1.8	0.3
Engineering and technology	66.3	19.6	7.8	4.6	1.4	0.3

FFRDC = federally funded research and development center

NOTE: Includes only references in U.S. papers to other U.S. papers.

See appendix table 5-39.

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Citation differences, by field (summarized in text table 5-10), provide an example of these variations. (See appendix table 5-39.) Academic articles, in particular, are prominently cited in the fields of biology, chemistry, and mathematics (relative to the average for all fields) and relatively less so in physics and in the earth and space sciences. Higher-than-average references to industry articles are evident in chemistry, physics, and engineering and technology. Among Federal Government articles, those in clinical medicine, biology, and the earth and space sciences are frequently cited (in this sense). For FFRDCs, articles are frequently cited in the earth and space sciences, engineering and technology, and, especially, physics. The role of the nonprofit sector in the biomedical sciences is evident as well.

Gradual shifts in these citation patterns have occurred since the first part of the 1980s. There is now a slightly greater tendency in all sectors (except industry itself) to cite industry articles and a greater tendency in all sectors (except academic papers) to cite academic articles. In turn, all sectors cite Federal articles somewhat less frequently. Industry cites FFRDC articles less often and cites nonprofit articles more often than in the past. (See text table 5-11.) While these changes appear numerically modest, they reflect a relative shift in the use of scientific and technical research results toward academia, industry, and, to a lesser extent, the nonprofit sector, and away from the Federal Government and FFRDCs.

Citations in U.S. Patents of the Scientific and Technical Literature

Scientific and technical articles cited on the first page of patent applications provide an indication of the potential contribution of published research results to patentable U.S. inventions.[57] Such citations of the research literature have risen rapidly in only a few years, and papers from the academic sector figure prominently in this increase.

For all U.S. patents issued in 1987–88 and 1993–94, references to U.S. research journal articles were identified. These articles were then classified according to their field and performer sector. (See appendix table 5-40.) In 1987–88, about 16,000 such citations were recorded; by 1993–94, this number had increased nearly threefold, to 47,400. Roughly half of the references were to papers from academic institutions; one-quarter were to industry papers, 9 percent to articles by Federal employees, another 8 percent to articles from the nonprofit sector, and 3 percent from FFRDC investigators. Academic articles gained a greater share of all citations in the most recent period, while the shares of industry, Federal Government, and FFRDC articles declined marginally.

Articles in biomedical research and clinical medicine accounted for 65 percent of all patent citations. In each sector but the FFRDCs, they received the bulk of citations, ranging from 44 percent in industry to 92 percent for nonprofit institutions. In contrast, 41 percent of FFRDC citations were to physics, another 19 percent were to engineering and technology, and 13 percent to chemistry.

[57]For a discussion of patenting, see Chapter 6, Technology Development and Diffusion. See also Academic Patenting in this chapter.

Text table 5-11.
Patterns of cross-sector citations, by citing sector

Citing sector	Academia	Industry	Federal	FFRDC	Nonprofit	Other
			1985–88 articles			
			Percent to cited sector			
United States, total	70.5	6.3	10.6	2.2	9.0	1.4
Academic institutions	77.1	4.3	8.0	1.6	7.7	1.2
Industry	46.9	36.1	8.1	2.7	5.2	1.0
Federal Government	52.2	4.4	32.9	1.3	7.6	1.5
FFRDCs	49.8	7.6	6.3	33.4	2.6	0.3
Nonprofit institutions	58.9	3.3	8.9	0.6	26.5	1.8
Other	59.1	3.6	12.0	0.5	10.9	13.9
			1990–93 articles			
United States, total	70.5	7.9	9.7	1.9	8.8	1.2
Academic institutions	76.5	5.9	7.5	1.5	7.6	1.0
Industry	47.8	35.7	7.8	1.8	5.9	0.9
Federal Government	52.4	6.5	31.1	1.4	7.3	1.3
FFRDCs	51.4	9.3	6.0	30.1	2.9	0.3
Nonprofit institutions	60.0	5.1	8.3	0.6	24.4	1.6
Other	60.5	5.5	11.6	0.7	11.0	10.7

FFRDC = federally funded research and development center
See appendix table 5-39.

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International Use of Scientific and Technical Articles in Subsequent Scientific Research

Previous sections have examined the U.S. position in the production of scientific and technical articles and its role in international scientific collaboration, as evidenced by its standing in the international coauthorship of articles published in leading peer-reviewed world journals. This section describes citations of this literature. Citations of a given output unit's (e.g., a country, sector, or institution) publications have often been treated as indicators of quality,[58] but this has not met with universal acceptance. Citations are discussed here in the more modest framework of "utility"; that is, they are treated as rough indicators of the degree of perceived usefulness of a country's articles to scientists elsewhere.

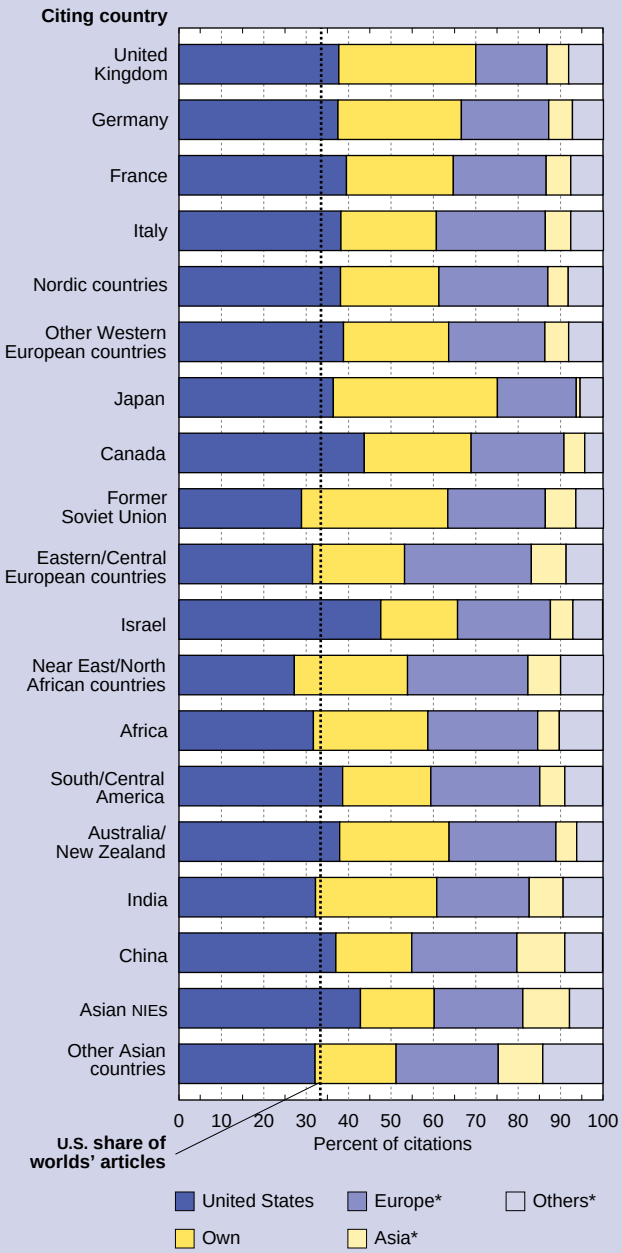
U.S. science and technology articles are cited in excess of the U.S. share of the world's publications by virtually all scientifically mature nations. (See appendix table 5-41.) Not surprisingly, all countries cite their domestic scientific and technical literature well in excess of their respective world shares. But no other country cites its domestic literature as heavily as the United States. Its 70-percent self-citation might conceivably reflect insularity or aloofness, but the high proportion of U.S. involvement in internationally coauthored articles suggests that this explanation is at best incomplete and perhaps untenable. In fact, a comparison of citations of the U.S. literature (the leftmost column in appendix table 5-41) with those of a nation's domestic publications (diagonal values) suggests a different conclusion.

In virtually all nations' journals, U.S. articles are cited more heavily—that is, they constitute a larger share of total citations—than articles appearing in domestic publications. (See figure 5-27.) There is no compelling logical reason why one country's literature should be cited in proportion to its world share by any other country. For example, no European country cites any other European country's literature to an extent approximating the cited country's world article share, even though many arrangements exist to foster intra-European collaboration and flows of scientific and technical knowledge. It appears fair to conclude that U.S. scientific and technical articles are found to be very useful by scientists elsewhere, as evidenced by the volume of references to the U.S. literature in other countries' scientific and technical articles.[59]

These findings hold, in general, for all major fields, but they are not determined by U.S. publication shares. (See appendix table 5-41.) For example, U.S. biomedical research articles generally receive citation shares well above the U.S. article share of 39 percent; the same pattern is true for physics articles. On the other hand, mathematics and biology articles tend to be cited below the U.S. world article shares in these fields.[60] (See *The Advent of Electronic Publishing.*)

Figure 5-27.

Citations to U.S. and other articles in world's scientific and technical literature, selected countries: 1990–93



NIE = newly industrialized economy
* = excludes citations to a country's own literature

See appendix table 5-41.

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[58]For a recent example, see National Academy Press (1995), which uses the citations to a graduate program faculty's publications as one measure of quality.

[59]This might be considered an indicator of "leadership."

[60]This raises an intriguing research puzzle that cannot be pursued here: What accounts for these citation patterns?

The Advent of Electronic Publishing

A recent article in *Scientific American* (Stix, 1994) discusses developments in electronic scientific communication including:

- Transfer of information about ongoing work, sharing of data, and virtual samples;
- Operation of virtual research teams;
- Circulation of research synopses, informal papers, preprints;
- Distribution of refereed articles;
- Electronic versions of hard-copy journals; and
- Fully electronic (virtual) journals.

All of these hold implications for the conduct of scientific work and the communication of its results. For the present discussion, the last three points are most salient. The electronic distribution of individual articles is occurring now and will soon become commonplace. Cost pressures on publishers will combine with the growing availability and ease of use of communication, search, and download technologies to make a wide variety of print journals available for electronic perusal. In both instances, the printed journal article remains the basic source of the information (i.e., the type of publication covered here). The electronic distribution of these articles or journals will not distort publication counts: Accessing is analogous to checking out a journal at the library or copying an article. However, electronic searches may make it easier to uncover relevant related work, which, in turn, might influence citation behavior.

The creation of virtual journals is a logical extension of these developments. The article names a few (mostly nonscience) examples and points out a difficulty in a transition to fully electronic publications. Refereed print journals are not mere distributors of the latest research results. They exercise quality control, and they serve to establish priority for a researcher's work, upon which the author's scientific recognition and prestige rests. Quite likely, some electronic equivalents of these functions will emerge; indeed, experimentation is underway. For example, the American Astronomical Society (AAS), with partial support from the NSF, is experimenting with an on-line version of its journals. Basically, AAS's approach is to build a fully peer-reviewed electronic journal version of its print-based publications, thus preserving the defining elements of the traditional scientific journal. Less formally structured experiments are already underway in a number of other fields, and by the time this volume goes to print, no doubt other such activities will have been added.

It is unclear whether electronic publications will supplement or supplant hard copy journals. In the immediate future, publications counts, and perhaps also citation patterns, are unlikely to be seriously affected by developments in the area of electronic communications. However, the torrid pace of change in these technologies suggests that "the immediate future" is best measured in years, not decades. Thus, new indicators of scientific research outputs will need to be developed for use alongside or in place of the measures discussed here. The nature of such indicators will depend on the emergent forms of electronic publishing. A major shift away from traditional print journals and into electronic media would, in any case, be reflected in the citations appearing in articles published in the set of core journals that currently form the basis for publications counts.

Academic Patenting

Patents Awarded to U.S. Universities

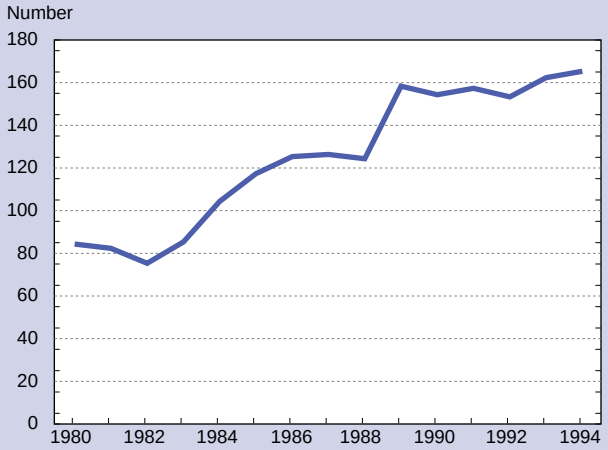
The U.S. Patents and Trademarks Office grants government-sanctioned property rights, in the form of patents, for inventions deemed to be new, useful, and nonobvious.[61] Patent grants may be awarded on the results of R&D that have potential utility for the development of new or improved products or processes, and a growing number of U.S. academic institutions are applying for, and receiving, such protection. While the bulk of academic R&D is basic research, (i.e., not undertaken to yield immediate practical applications), data on the patenting activity of universities and colleges suggest that academic institutions are giving increased attention to the potential economic benefits inherent in their R&D results and that they are seeking to capture some of these benefits.[62]

A growing number of academic institutions are receiving patents, with growth being especially pronounced during the 1980s. (See figure 5-28.) During the 1970s, the number of institutions receiving at least one patent grew slowly, but during the 1980s, the number more than doubled, from 80 in 1980 to 165 in 1994. This development affected both public and private institutions: The number of public universities and colleges receiving patents rose from 51 to 97; private institutions increased

[61]Chapter 6, Technology Development and Diffusion, presents a more comprehensive discussion of patented inventions in all U.S. sectors, placed in a world context.

[62]Patents are partial and ambiguous indicators of inventive activity. Patents may be used to forestall possible competitive action, solidify one's own position, or other ends. Not all sectors and industries rely on patents. For a complete discussion of the problems associated with this indicator, see Chapter 6, Technology Development and Diffusion.

Figure 5-28.
Number of academic institutions granted patents



NOTE: Data have been aggregated to the institutional level and, in some cases, refer to entire systems (e.g., California and Massachusetts).

See appendix table 5-42.

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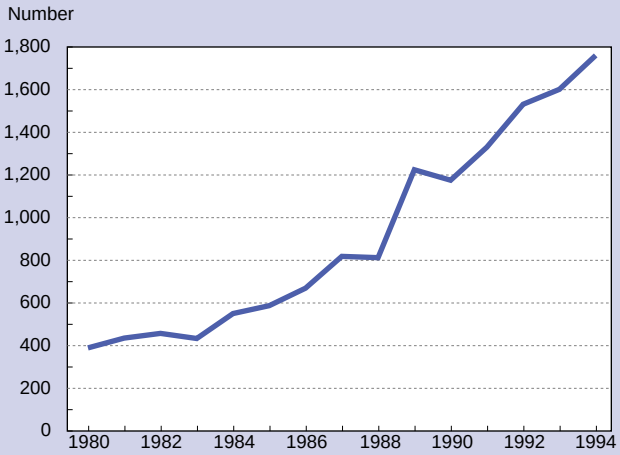
Figure 5-29.
Number of patents granted to U.S. academic institutions



See appendix table 5-42.

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from 29 to 58. Patenting by the research universities grew more rapidly than by other institutions. During the 1980s, just as a growing number of academic institutions were receiving patents, the share of the 100 largest research universities (by volume of total research funds) increased from 75 to about 85 percent (where it has leveled off) of all newly issued academic patents. (See appendix table 5-42.) At the same time, a composition shift took place within the top 100: The share of the largest 20 universities contracted, while institutions that rated below 50 in research volume gained a slowly growing share of these patents.

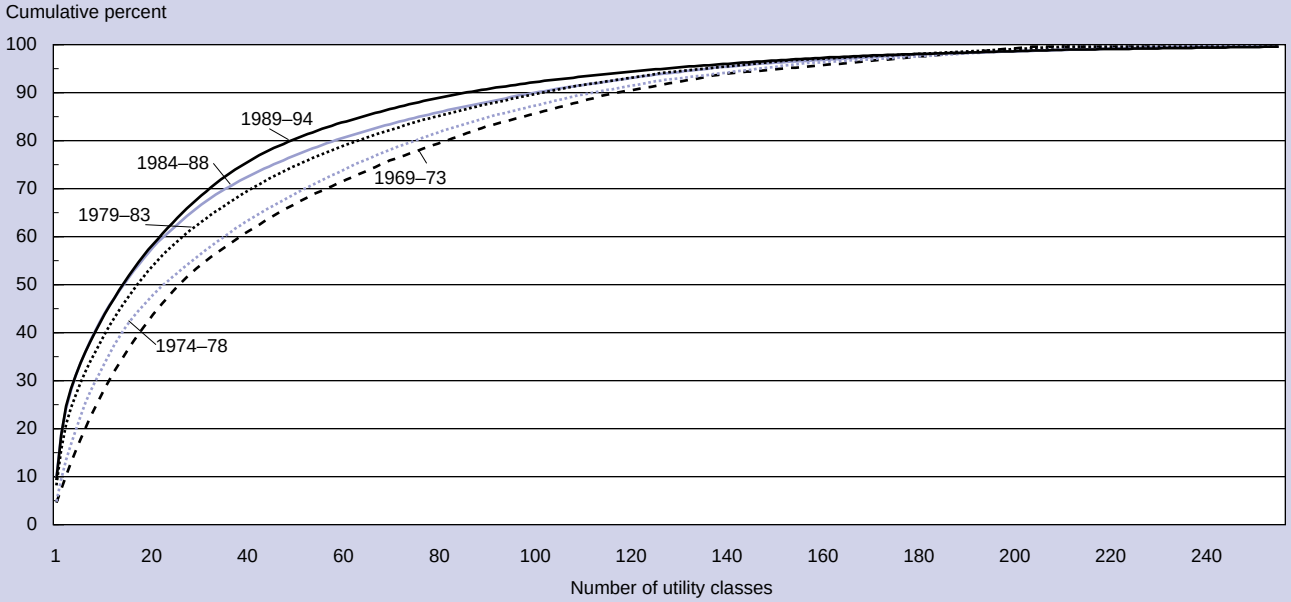
The number of patents awarded to U.S. universities rose sevenfold in 2 decades. This is a rapid growth rate, even considering the relatively low base. From an average of 200 to 300 patents a year issued in the late 1960s and early 1970s, the number rose to 350 to 400 a year in the early 1980s; it then increased fourfold to 1,761 in 1994. (See figure 5-29.) This growth is far steeper than that of all U.S. patent awards, which roughly doubled in number. A change in U.S. patent law in 1980, which allowed academic institutions and small businesses to retain title to inventions resulting from federally supported R&D, may have contributed to the continuing strong increase in academic patenting. A recent report (Henderson, Jaffe, and Trajtenberg, 1995) discusses this and other reasons—such as increased focus on commercially relevant technologies and the creation and increasing sophistication of university units specializing in technology transfer (on this point, also see Income from Patenting and Licensing Arrangements in this section)—but calls the causes unclear. In fact, 44 percent of all U.S. academic patents issued from 1969 through 1994 were awarded in 1990–94, well after the legal change took effect. University patents now make up about 3 percent of all U.S. patent awards, compared with a mere one-half percent only 2 decades ago. The same report notes, however, that the average commercial importance of new academic patents may be leveling off.

Patents are divided into utility classes, according to their likely areas of application. The distribution of all patents over these classes has slowly evolved; for academic patents, the changes have been more pronounced and rapid. (See figure 5-30 for the relative degree of concentration of university patents, by number of utility classes, and appendix table 5-43 for a breakdown of academic patents, by major utility class.) It shows an increasing concentration of patents in a smaller set of utility classes. For example, in 1969–73, patents in somewhat more than 80 different utility classes accounted for 80 percent of all university patenting. By the early 1990s, a mere 50 utility classes accounted for a comparable share. Three utility classes in particular have been prominent. Class 435 (defined by the U.S. Patent Office as chemistry: molecular biology and microbiology) and 424 and 514 (drug: bio-affecting and body-treating compositions) grew from about 8 percent of academic patents in the early 1970s to fully one-quarter of the total in the early 1990s. (See figure 5-31.)

Income from Patenting and Licensing Arrangements

Universities increasingly are negotiating royalty and licensing arrangements based on their patents. A 1992 report by the U.S. GAO, based on a survey of 35 universi-

Figure 5-30.
Cumulative distribution of patent awards to U.S. academic institutions, by number of utility classes



See appendix table 5-43.

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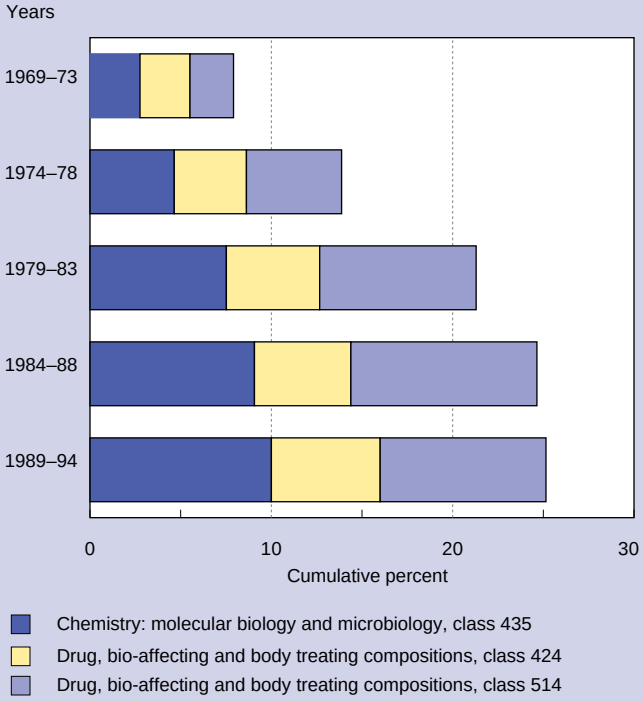
Figure 5-31.
Fraction of total U.S. academic patents in three utility classes



See appendix table 5-43.

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ties, found that, as a group, they had granted 536 licenses (197 exclusive and 339 nonexclusive) in 1989–90. GAO reported that most of these universities had substantially expanded their technology transfer programs during the 1980s. Typical licensees were small U.S. pharmaceutical, biotechnology, or medical businesses. During 1989–90, the reported income flows based on these licenses were modest: a total of $82 million. However, just as patenting has expanded, so has licensing and the attendant revenue flows. A more recent survey conducted by the Association of University Technology Managers[63] reported gross revenues received by U.S. universities of $242 million in 1993, compared to $172 million in 1992. Part of the increase, however, is likely to be due to more extensive coverage and accounting. Nevertheless, while total reported revenue remains modest in comparison with the underlying R&D volume, its strong upward trend suggests a growing willingness on the part of universities to attend to the applications potential of the research conducted on their campuses and a growing willingness on the part of entrepreneurs and companies to recognize and invest in the market potential of this research.

[63]Association of University Technology Managers, Inc. (1994).

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