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Chapter 5
Academic Research and Development

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Highlights

Spending and Funding for Academic R&D

In 2009, U.S. academic institutions spent $54.9 billion on science and engineering R&D and an additional $2.4 billion in non-S&E fields.

- In 2009, academic institutions performed nearly half (53%) of the nation's total basic research, a percent that has risen steadily from 47% in the later 1980s.
- Academia performed 36% of all U.S. research (basic plus applied) and 14% of total U.S. R&D.
- Higher education's share of total U.S. research expenditures (basic plus applied) has gradually increased, rising from 24% in 1982 to 36% in 2009.

The federal government provides the bulk of funds for academic R&D; during the past two decades, its share has fluctuated around 60%.

- The federal government provided 59% ($32.6 billion) of the $54.9 billion of academic spending on S&E R&D in FY 2009. The federal share was somewhat higher in the 1970s and early 1980s.
- Six agencies provide almost all (97% in 2009) federal academic R&D support—the National Institutes of Health, National Science Foundation, Department of Defense, National Aeronautics and Space Administration, Department of Energy, and Department of Agriculture.

The bulk of academic R&D funding from nonfederal sources is provided by the universities themselves.

- The share of support provided by institutional funds increased steadily between 1972 (12%) and 1991 (19%) but since then has remained fairly stable at roughly one-fifth of total academic R&D funding.
- Industry's percentage of funding for academic R&D declined steeply after the 1990s, from above 7% in 1999 down to about 5% by 2004, but has seen a 5-year increase to about 6% in 2009.
- Support from other governmental agencies, chiefly state funds, declined from 10% in the late 1970s to about 8% through the 1990s and stood at less than 7% in 2009.

Over the last 20 years, the distribution of academic R&D expenditures across the broad S&E fields shifted in favor of life sciences and away from physical sciences.

- In 2009, the life sciences represented the largest share (60%) of expenditures in academic S&E R&D.
- Over the last 20 years, the life sciences were the only broad field to experience a sizable increase in share—6 percentage points—of total academic R&D. Over the same period, the physical sciences share of total academic R&D dropped 3 percentage points.

Infrastructure for Academic R&D

Research space at academic institutions has continued to grow annually over the last 20 years. Nonetheless, the pace of growth has noticeably slowed in the last few years.

- Total research space at research-performing universities and colleges was 2.2% greater at the end of 2009 than it was in 2007, continuing a two decade long period of expansion.
- The rate of annual increase for all S&E fields combined in the 2001–03 period was 11%, but it has gradually slowed since then. Unlike in other fields, in recent years research space for the biological/biomedical sciences and agricultural sciences has continued to expand at substantial rates.

In 2009, about $2.0 billion in current funds was spent for academic research equipment (i.e., movable items such as computers or microscopes), a 2% increase over 2008, after adjusting for inflation.

- Equipment spending as a share of total R&D expenditures fell from 4.8% in FY 1999 to a three decade low of 3.6% in FY 2009.
- Three S&E fields accounted for 82% of equipment expenditures in 2009: the life sciences (41%), engineering (24%), and the physical sciences (17%).
- In FY 2009, the federal share of support for all academic research equipment funding was 55%. This share has fluctuated between 55% and 63% over the last 20 years.

Cyberinfrastructure

Academic networking infrastructure is rapidly expanding in capability and coverage.

- Research performing institutions had more connections, bandwidth, and campus coverage compared with earlier in the decade.
- Colleges and universities reported external network connections with greater bandwidth, faster internal network distribution speeds, more connections to high-speed networks, and greater on-campus wireless coverage.
- In FY 2003, 66% of institutions had bandwidth of less than 1 gigabit per second and no institutions had speeds faster than 2.5 gigabits per second. By FY 2009, 82% of institutions had bandwidth speeds of 1 gigabit per second or faster and 24% had speeds faster than 2.5 gigabits per second.

Doctoral Scientists and Engineers in Academia

The size of the doctoral academic S&E workforce was an estimated 272,800 in 2008, almost unchanged from 2006. Total academic doctoral employment grew less in this period than in any comparable period since 1973.

Full-time faculty positions, although still the predominant type of employment, increased more slowly than postdoc and other full- and part-time positions.

- The share of all S&E doctorate holders employed in academia dropped from 55% in 1973 to 44% in 2008.
- The percentage of S&E doctorate holders employed in academia who held full-time faculty positions declined from 88% in the early 1970s to 73% in 2008. Over that same period, other full-time positions rose from 6% to 15% of total academic employment, and postdoc and part-time appointments increased from 4% and 2% to 7% and 6%, respectively.

The demographic profile of academic researchers shifted substantially between 1973 and 2008. The increasing proportion of women was a particularly striking change.

- The number of women in academia increased more than eightfold between 1973 and 2008, from 10,700 to about 93,400, raising their share of all academic S&E doctoral employment from 9% to 34%. Women employed as full-time doctoral S&E faculty increased from 7% to 31%.
- In 2008, underrepresented minorities (blacks, Hispanics, and American Indians/Alaska Natives) constituted about 9% of both total academic S&E doctoral employment and full-time faculty positions, up from 2% in 1973.
- The foreign-born share of U.S. S&E doctorate holders in academia increased from 12% in 1973 to nearly 25% in 2008, and nearly half (46%) of postdoc positions in 2008 were held by foreign-born U.S. S&E doctorate holders. No comparable data exist for foreign-born, foreign-degreed doctorate holders.

Between 1973 and 2008, the number of academic researchers with S&E doctorates more than doubled. Among full-time faculty, the balance of emphasis in work activity shifted toward research and away from teaching. Young faculty—those within 3 years of a doctorate award—were less likely than other faculty to report research as a primary work activity.

- About two-thirds of doctoral scientists and engineers employed in academic institutions in 2008 were engaged in research as either a primary or secondary work activity. The proportions of researchers were highest in the life sciences, engineering, and computer sciences.
- The share of full-time S&E faculty identifying research as their primary work activity climbed from 19% in 1973 to 36% in 2008, while the share identifying teaching as their primary activity fell from 68% to 47%.
- In 2008, 33% of recently degreed S&E doctoral faculty identified research as their primary work activity, a smaller share than reported by faculty cohorts who had earned S&E doctorate degrees 4 to 7 years earlier (48%), 8 to 11 years earlier (41%), and 12 or more years earlier (35%).

A substantial pool of academic researchers—including graduate research assistants and doctorate holders employed in postdoc positions—has developed outside the ranks of full-time faculty.

- The number of S&E doctorate holders employed in academic postdoc positions climbed from 4,000 in 1973 to 18,000 in 2008.
- In 2008, 36% of recently degreed S&E doctorate holders in academia were employed in postdoc positions, a figure that approached the share (42%) employed in full-time faculty positions. Among S&E doctorate holders 4 to 7 years beyond their doctorate degrees, 11% held postdoc positions.

For S&E as a whole and for many fields, the share of academic S&E doctorate holders receiving federal support declined since the early 1990s.

- Throughout the 1973–2008 period, fewer than half of full-time S&E faculty received federal support, whereas the share of postdocs who received federal support was more than 70%.
- Among full-time faculty, recent doctorate recipients were less likely to receive federal support than their more established colleagues.

Outputs of Academic S&E Research: Articles and Patents

S&E article output worldwide grew at an average annual rate of 2.6% between 1999 and 2009. The U.S. growth rate was much lower, at 1.0%.

- The United States accounted for 26% of the world's total S&E articles in 2009, down from 31% in 1999. The share for the European Union also declined, from 36% in 1999 to 32% in 2009.
- In Asia, average annual growth rates were high—for example, 16.8% in China and 10.1% in South Korea. In 2009, China, the world's second-largest national producer of S&E articles, accounted for 9% of the world total.
- Very rapid annual growth rates of over 10% between 1999 and 2009 were also experienced by Iran, Thailand, Malaysia, Pakistan, and Tunisia. However, some of these countries had low S&E article production in 1999.

Two-thirds of all S&E articles were coauthored in 2010. Articles with authors from different institutions and different countries have continued to increase, indicating increasing knowledge creation, transfer, and sharing among institutions and across national boundaries.

- Coauthored articles grew from 40% of the world's total S&E articles in 1988 to 67% in 2010. Articles with only domestic coauthors increased from 32% of all articles in 1988 to 43% in 2010. Internationally coauthored articles grew from 8% to 24% over the same period.

- U.S.-based researchers were coauthors of 43% of the world's total internationally coauthored articles in 2010.
- Three other nations—Germany, the United Kingdom, and France—had high, though declining, shares of international coauthorships. Chinese authors increased their share of the world's internationally coauthored S&E articles from 5% to 13% between 2000 and 2010.
- In the United States, because of the predominance of the academic sector in S&E article publishing, academic scientists and engineers have been on the forefront of the integration of S&E research across sectors. In non-academic sectors, cross-sector coauthorship with academic authors ranged from 55% to 76% in 2010.

Like indicators of international coauthorship, cross-national citations provide mixed evidence of changes in the worldwide scope, influence, and quality of U.S. S&E research.

- Between 2000 and 2010, the U.S. share of the world's total citations in S&E articles declined from 45% to 36%, reflecting the broad expansion of the global literature. China's share of these citations increased from 1% to 6%. The EU share remained steady at 33%, and Japan's share fell from 7% to 6%.
- The percentage of U.S.-authored S&E articles receiving the highest number of citations—an indicator of quality and impact on subsequent research—has changed little. In 2010, U.S. articles represented 28% of all articles in the cited period, but 49% of the articles in the top 1% of all cited articles.

Data on citations per publication suggest that the quality of U.S.-authored articles has changed little over the past 10 years.

- In 2010, articles with U.S. authors were highly cited about 76% more often than expected based on the U.S. share of world articles, compared to 85% in 2000. Between 2000 and 2010, EU-authored articles improved on this indicator, from 27% *less* often than expected to 6% *less* often.
- In 2010, China's rate of high citation was nearly equal to its rate of publication in engineering and computer science, but its citation rate did not exceed its publication rate in any field. In most broad fields, China's rate of high citations compared to its publication rate was higher in 2010 than in 2000.

U.S. Patent and Trademark Office (USPTO) data show that annual patent grants to universities and colleges ranged from 2,900 to 4,500 between 1998 and 2010.

- College and university patents have been about 4.2% to 4.7% of U.S. nongovernmental patents for a decade. Biotechnology patents accounted for most U.S. university patents in 2010, at 30%, a percentage that has grown over the past 15 years.
- Data from the Association of University Technology Managers (AUTM) indicate continuing growth in a number of patent-related activities. Invention disclosures grew from 12,600 in 2002 to 18,200 in 2009. New U.S. patent applications filed by AUTM university respondents also increased, from 6,500 in 2001 to 11,300 in 2009. In contrast, the number of issued patents reported by AUTM respondents has remained flat.

Chapter Overview

U.S. universities and colleges occupy a unique position in the nation's overall R&D system. They perform more than half of U.S. basic research and, because they link graduate education and research, prepare the next generation of researchers (see chapter 2).

This chapter discusses the role of the academic sector within the national R&D enterprise. The first section examines trends in spending and funding for academic R&D, identifies key funders of academic R&D, and describes the allocation of funds across academic institutions and S&E fields.

Because the federal government has been the primary source of funding for academic R&D for more than half a century, the importance of federal agency support for overall R&D and for individual fields is explored in some detail. Other significant sources of funding include the institutions themselves, businesses, and state and local government. The first section also traces recent changes in the distribution of funds among academic institutions and the types of academic institutions that receive federal R&D support.

The chapter's second section reviews the status of infrastructure for academic R&D. This discussion provides data on the current trends in academic research facilities, research equipment, and cyberinfrastructure.

The next section discusses trends in the employment of academic doctoral scientists and engineers. Major trends examined include the numbers of academic doctoral scientists and engineers, their changing demographic composition, and the types of positions they hold. This section also examines employment patterns in the segment of the academic workforce that is engaged in research, with particular attention to full-time faculty, postdocs, graduate research assistants, and the academic scientists and engineers receiving research support from the federal government.

The chapter concludes with an analysis of trends in two types of research outputs: S&E articles and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in chapter 2.) This section looks at the volume of research articles for selected countries/regions and focuses (when appropriate) on S&E articles by U.S. academic researchers. Coauthored articles, both across U.S. sectors and internationally, are indicators of increasing collaboration in S&E research. The number of influential articles from U.S. institutions, as measured by the frequency with which they are cited, is examined and compared with citations to S&E articles produced around the globe.

The final section explores academic patenting activities and examines patents, licenses, and income from these as forms of academic R&D output. Patent citations to the S&E literature are also examined, with some attention—new in this edition—to S&E literature citations in patents for clean energy and related technologies.

Expenditures and Funding for Academic R&D

Academic R&D is a key part of the overall U.S. R&D enterprise.[1] Academic scientists and engineers conduct the bulk of the nation's basic research and are especially important as a source of the new knowledge that basic research produces. Indicators tracking the status of the financial resources, the research facilities, and the instrumentation that are used in this work are discussed in this and the next section of the chapter. (For an overview of the sources of data used see the sidebar, "Data on the Financial and Infrastructure Resources for Academic R&D.")

Academic R&D in the National R&D Effort

Expenditures by U.S. colleges and universities on R&D in S&E fields totaled $54.9 billion in 2009.[2] Academic spending in non-S&E fields that year was another $2.4 billion. The corresponding figures for 2008 were $51.9 billion and $2.2 billion. In 2004, these figures were $43.3 billion and $1.6 billion, respectively.

Academic R&D spending is primarily for research (basic and applied)—in 2009, about 96% was spent on research (75% basic, 22% applied) and almost 4% was spent on development.[3] These shares are not appreciably different from the proportions that prevailed 5 and 10 years ago (appendix table 5-1).

Universities and colleges performed about 14% of all U.S. R&D in 2009. Higher education's prominence as a national R&D performer has generally increased over the last 30 years, rising from about 10% of all R&D performed in the United States in the early 1970s to an estimated 14% in 2009 (figure 5-1).

Universities and colleges accounted for just under 36% of all U.S. research in 2009. This was slightly higher than the 35% reported in 2002—and the previously highest share of the U.S. research total over the last 30 years (figure 5-1).

In regard to basic research, the academic sector is by far the country's largest performer. In 2009, it accounted for 53% of all the basic research performed in the United States. Indeed, institutions of higher education have accounted for more than half of all U.S. basic research since 1998 (figure 5-1).

(For a comparison of the academic R&D profiles of other countries, see the section on "International R&D Comparisons" in chapter 4.)

Sources of Support for Academic R&D

Academic R&D relies on funding support from a variety of sources, including the federal government, universities' and colleges' own institutional funds, state and local government, industry, nonprofits, and other organizations. Nevertheless, the federal government has consistently provided the majority of funding.

Data on the Financial and Infrastructure Resources for Academic R&D

Data on the financial and infrastructure resources supporting U.S. academic R&D are drawn from three ongoing National Science Foundation (NSF) surveys:

- Survey of Research and Development Expenditures at Universities and Colleges
- Survey of Science and Engineering Research Facilities
- Survey of Federal Funds for Research and Development.

The data definitions and classifications in these three surveys are similar, but not identical. Furthermore, the respondents differ across the surveys: universities and colleges for the first two, federal agencies for the third.

Some of the data presented in the first part of this section (see "Academic R&D in the National R&D Effort") come from the NSF's *National Patterns of R&D Resources* series, which integrates data from NSF's R&D expenditure surveys to yield a comprehensive account of national R&D spending and funding. These separate data sets are adjusted for internal consistency and to reflect a calendar year. Some of the *National Patterns* figures for 2009 are considered "preliminary."

The data subsequently covered are derived from the Survey of Research and Development Expenditures at Universities and Colleges. These data are not adjusted and represent reporting on an academic year basis (e.g., FY 2009 covers July 2008 through June 2009).

Data on "Top Agency Supporters" and "Agency Support by Character of Work" come from NSF's Survey of Federal Funds for Research and Development, which collects data on the R&D obligations of 30 federal agencies for each federal fiscal year (e.g., FY 2009 covers October 2008 through September 2009). The 2009 federal funds figures remain preliminary.

The federal obligations data for academic R&D (e.g., $26.0 billion in FY 2008) do not match the federally funded expenditures data reported by academic institutions (e.g., $31.3 billion in 2008). Several factors account for this discrepancy: the spans of the academic and federal fiscal years differ slightly, there is a time lag between obligating and spending funds, awards may span multiple years, and federal funds passed to other recipient organizations are sometimes double-counted.

The data on research equipment come from the Survey of Research and Development Expenditures at Universities and Colleges. The data on research facilities and cyberinfrastructure come from the Survey of Science and Engineering Research Facilities. In these surveys, academic R&D expenditures are reported by academic fiscal year.

Research equipment is purchased from operating funds and included in R&D expenditures. Although some large instrument systems may be classified as either facilities or equipment, facilities are generally treated as capital projects for accounting purposes.

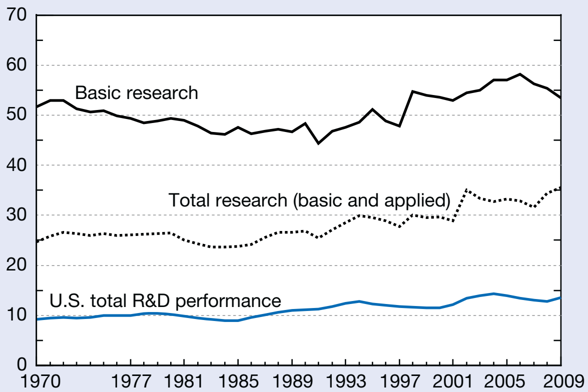
The survey population for the facilities survey includes all universities and colleges in the Academic R&D Expenditures survey with $1 million or more in R&D expenditures. Starting in 2003, the facilities survey included data on computing and networking capacities. Fixed items such as buildings, which often cost millions of dollars, are not included in the reported R&D expenditures.

Redesign of the Survey of R&D Expenditures at Universities and Colleges

NSF's Survey of Research and Development Expenditures at Universities and Colleges has been conducted annually since 1972. In 2007, an effort was started to evaluate and redesign the survey. The goals of the redesign were (1) to update the survey instrument to reflect current accounting principles in order to obtain more valid and reliable measurements of the amount of U.S. academic R&D expenditures and (2) to expand the current survey items to collect some additional detail on topics most often requested by data users. Data from the revised and expanded survey, renamed the "Higher Education R&D (HERD) Survey," is expected to be publicly available in late 2011.

The HERD survey will continue to capture comparable information on R&D expenditures by sources of funding and field, which will allow for continued trend analysis. It will also include a more comprehensive treatment of S&E and non-S&E fields, an expanded population of surveyed institutions, explicit treatment of research training grants and clinical trials, greater detail about the sources of funding for R&D expenditures by field, and headcounts on principal investigators, other research personnel, and postdocs. Britt (2010) provides a more complete list of improvements in the redesigned survey.

Figure 5-1
Academic share of U.S. R&D performance: 1970–2009

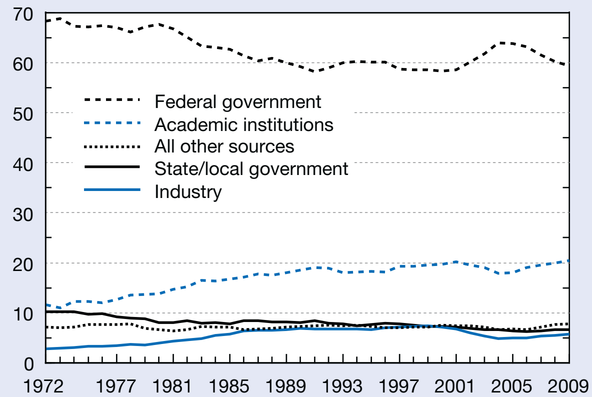


NOTES: Data based on annual reports by performers. Because of changes in survey procedures, character of work data before FY 1998 are not directly comparable with later years.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, National Patterns of R&D Resources (annual series). See appendix table 5-1.

Science and Engineering Indicators 2012

Figure 5-2
Academic R&D expenditures, by source of funding: 1972–2009

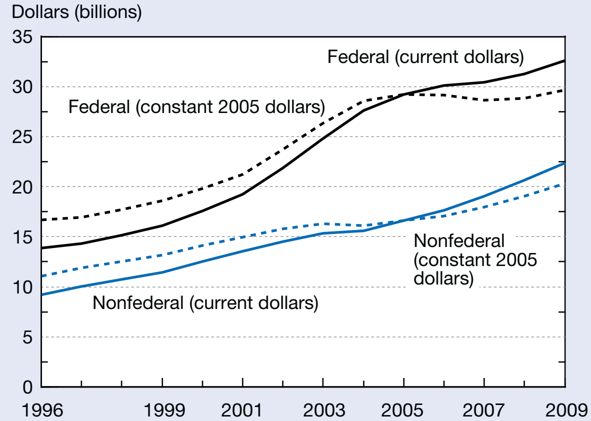


NOTE: Science and engineering R&D; non-S&E R&D not included.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges. See appendix table 5-2.

Science and Engineering Indicators 2012

Figure 5-3
Federal and nonfederal funding of academic R&D expenditures: 1996–2009



NOTES: Science and engineering R&D; non-S&E R&D not included. See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2005 dollars.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges. See appendix table 5-2.

Science and Engineering Indicators 2012

Federal Funding

The federal government provided $32.6 billion (59%) of the $54.9 billion of academic spending on S&E R&D in FY (academic) 2009.[4] The federal share was somewhat higher in the 1970s and early 1980s, although the federal government has long contributed the majority of funds for academic R&D (figure 5-2 and figure 5-3).

This $32.6 billion of federal funding in FY 2009 was 4.2% above the level of the previous year. The rates of growth in 2008 and 2007 were 2.8% and 1.0%, respectively. Over the previous 10 years, the level of federal funding for academic R&D has been consistently up, averaging 3.3% annually for the 5-year period of 2004–09 and 7.3% annually for the 10-year period of FY 1999–2009. But when adjusted for inflation, the 5-year annual average increase was 0.8% and the 10 year average was 4.8%—FY 2006 and 2007 were years with constant dollar declines in federal funding.

An additional perspective on funding trends is provided by inflation-adjusted obligations for academic S&E R&D reported by the federal agencies (i.e., the funds in constant dollars going to academic institutions in a given federal fiscal year that will be spent on R&D activities in the current and subsequent years). In constant 2005 dollars, federal academic R&D obligations peaked in FY 2004 at $25.0 billion, fell in the three subsequent years, reaching $24.0 billion in FY 2008, and then spiked upward in FY 2009, reaching $28.8 billion (appendix table 5-3).

Federal obligations for S&E R&D grew more than 10% each year on a constant dollar basis between FY 1998 and 2001. This reflected, for the most part, the federal commitment to double the R&D budget of the National Institutes of Health (NIH) over a 5-year period. Between FY (federal) 1998 and 2004, NIH's share of federal academic R&D funding increased from 57% to 63%. Then in FY 2009, the American Recovery and Reinvestment Act (ARRA), which was signed into law on February 17, 2009, provided an additional $18.3 billion in appropriations for federal R&D and R&D facilities and equipment in FY 2009.[5] The significant uptick in obligations observed in FY 2009 reflects the presence of nearly $5 billion of these ARRA funds (appendix table 5-3).

Top Federal Agency Supporters

Six agencies are responsible for the vast majority of annual federal obligations for higher education R&D: the National Institutes of Health (NIH), National Science Foundation (NSF), Department of Defense (DOD), National Aeronautics and Space Administration (NASA), Department of Energy (DOE), and Department of Agriculture (USDA). In federal FY 2009, these six agencies represented about 96% of the estimated $31.6 billion obligated for S&E R&D that year (appendix table 5-3).[6]

NIH is by far the largest funder, providing about 65% of total federal academic R&D obligations in FY 2009. NSF provided 13%; DOD, 9%; NASA, 3%; DOE, 4%; and USDA, 3%.

The federal government's overall support for academic R&D is the combined result of numerous discrete funding decisions made by the R&D-supporting federal agencies, all of which have differing missions and objectives, which in turn affect the priorities for research funding in the academic sector. For the most part, federal R&D funding to the higher education sector is allocated through competitive peer review. Nevertheless, congressional priorities and concerns in the course of the annual federal budget process can influence funding outcomes—see the sidebar, "Congressional Earmarks."

Congressional Earmarks

Broadly defined, academic earmarking is the congressional practice of directing federal funds to educational institutions for facilities or projects that are not required to undergo merit-based peer review. However, this characterization contains enough ambiguity about how to classify individual projects that estimates of the number of earmarked projects or the amount of earmarked funds may reasonably differ.

Detailed assessments of academic earmarks have been prepared by staff of *The Chronicle of Higher Education*. The most recent of these analyses estimated a total of $2.3 billion in academic earmarks in FY 2008 (Brainard and Hermes, 2008). A similar analysis for FY 2003 puts the academic earmark total at $2.0 billion (Brainard and Borrego, 2003). Approximately two-thirds ($1.6 billion) of the FY 2008 funds and $1.4 billion of the FY 2003 funds were for R&D projects, R&D equipment, or construction or renovation of R&D laboratories. A more recent estimate, published in the *Chronicle* but prepared by an outside watchdog group, put the academic earmark total for FY 2010 at $1.5 billion (Kiley, 2010).

Recently, both the Senate and House of Representatives agreed to federal budget rules that aim to eliminate earmarks. There are no earmarks in the final budget appropriations for FY 2011.

Federal Agency Support by Character of Work

Basic research activities represented about 58% of federal obligations for academic R&D in FY 2009 and about 56% in both FY 2007 and 2008 (appendix table 5-4). The two agencies funding the majority of basic research in the academic sector were NIH and NSF.

Applied research represented about 38% of federal obligations for academic R&D in FY 2009, 37% in FY 2008, and 38% in FY 2007. NIH provided the vast majority of funding in this category. Federal obligations for development activities in academia were 4–7% throughout FY 2007–09, with DOD and NASA the principal funders.

Other Sources of Funding

Notwithstanding the continuing dominant federal role in academic R&D funding, funding from nonfederal sources has grown steadily in recent years (figure 5-3). Adjusted for inflation, annual growth in nonfederal funding for academic R&D has averaged 4.8% over the last 5 years, and 4.4% for the last 10 years. The corresponding growth rates for federal funding have been 0.8% and 4.8%.

- **University and college institutional funds**. In FY 2009, institutional funds from universities and colleges comprised the second largest source of funding for academic R&D, accounting for about 20% ($11.2 billion) of the total (appendix table 5-2). Institutional funds encompass institutionally financed research expenditures and unrecovered indirect costs and cost sharing. They exclude departmental research, which is a more informal type of research that is usually coupled with instructional activities in departmental budget accounts and thus does not meet the Office of Management and Budget definition of organized research. The share of support represented by institutional funds increased steadily from 12% in 1972 to 19% in 1991, and it has remained near 20% in the subsequent years. Funds for institutionally financed R&D may derive from general-purpose state or local government appropriations; general-purpose awards from industry, foundations, or other outside sources; endowment income; and gifts. Universities may also use income from patents and licenses or revenue from patient care to support R&D. (See section "Patent-Related Activities and Income" later in this chapter for a discussion of patent and licensing income.)
- **State and local government funds.** State and local governments provided 7% ($3.6 billion) of higher education R&D funding in FY 2009. Although their absolute funding total has continued to rise annually, their funding share has declined from a peak of 10% in the early 1970s to below 7% in recent years. However, these figures are likely to understate the actual contribution of state and local governments to academic R&D, particularly for public institutions, because they only reflect funds that these governments directly target to academic R&D activities.[7] They exclude any general-purpose state or local government appropriations that academic institutions designate and use to

fund separately budgeted research or pay for unrecovered indirect costs—such funds are categorized as institutional funds. (See chapter 8, "State Indicators," for some indicators of academic R&D by state.)

- **Industry funds.** Industrial support accounts for the smallest share of academic R&D funding (just under 6%), and support for academia has never been a major component of industry-funded R&D. After a 3-year decline between 2001 and 2004, industry funding of academic R&D has been steadily increasing, reaching $3.2 billion in FY 2009. (See appendix table 4-5.)
- **Other sources of funds.** In FY 2009, all other sources of support accounted for 8% ($4.3 billion) of academic R&D funding, a level that has stayed about the same since 1972. This category of funds includes, but is not limited to, grants and contracts for R&D from nonprofit organizations and voluntary health agencies.

EPSCoR

The Experimental Program to Stimulate Competitive Research (EPSCoR) is a long standing multi-agency federal program that has the objective of improving the geographical distribution of federal support for academic R&D. An overview of the program and recent statistics on its activities are discussed in the sidebar EPSCoR: The Experimental Program to Stimulate Competitive Research.

Academic R&D Expenditures by Field

Investment in academic R&D has long been concentrated in the life sciences, which have received more than half of all academic R&D expenditures for more than three decades.

Science and Engineering R&D

In FY 2009, academic R&D in the life sciences accounted for $32.8 billion (60%) of the $54.9 billion academic S&E R&D total (appendix table 5-5). Within the life sciences, the medical sciences accounted for 33% of the academic total and the biological sciences accounted for another 18%.[8]

Adjusted for inflation, academic R&D expenditures in the medical sciences increased by more than 75% from FY 1990 to FY 2000, and by almost 65% from FY 2000 to FY 2009 (figure 5-4 and appendix table 5-6). This sizable increase shifted the distribution of academic R&D expenditures (figure 5-5). The life sciences gained more than 4 percentage points in financial share over the decade of the 1990s (from 54% to 58%) and nearly another 2 percentage points since 2000 (up to 60%). By contrast, the physical sciences lost 2 percentage points in share over FY 1990–2000 (from 11% to 9%) and an additional percentage point since FY 2000 (down to 8%).

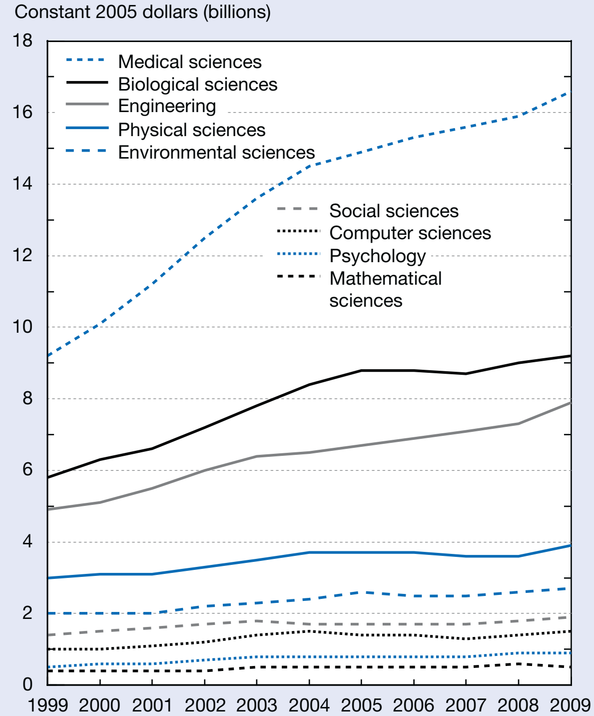
Federal R&D Funds by Field

R&D projects in the life sciences also constitute a majority of federally supported academic S&E R&D. They accounted for $19.3 billion (59%) of the $32.6 billion of federal support in FY 2009 (appendix table 5-7). The Department of Health and Human Services (HHS)—of which NIH is a part—supports the vast majority of this life science funding (83%). By contrast, and while their shares of total academic R&D funding are much smaller, DOD, DOE, NASA, and NSF have more diversified funding patterns (figure 5-6). In FY 2009, NSF was the lead federal funding agency for academic research in the physical sciences (30% of federally funded R&D expenditures), mathematics (56%), computer sciences (40%), and environmental sciences (34%). DOD was the lead funding agency in engineering (32%).

Federal funding has played a larger role in overall support for some fields than others (appendix table 5-8). The federal government is the dominant funder in fields such as the atmospheric sciences (78% in FY 2009), physics (73%), and aeronautical/astronautical engineering (70%). But it plays a much smaller role in other fields, such as economics (32% in FY 2009), political science (37%), and agricultural sciences (28%).

The federally financed proportion of R&D spending in *all* of the broad S&E fields has been stable or increased since 1990 (appendix table 5-8). This reverses the trend between 1975 and 1990, when the federal share had declined in all the broad fields.

Figure 5-4
Academic R&D expenditures, by S&E field: 1999–2009



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2005 dollars.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges. See appendix table 5-6.

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EPSCoR: The Experimental Program to Stimulate Competitive Research

EPSCoR, the Experimental Program to Stimulate Competitive Research, is based on the premise that universities and their S&E faculty and students are valuable resources that can potentially influence a state's development in the 21st century in much the same way that agricultural, industrial, and natural resources did in the 20th century.

EPSCoR originated as a response to a number of stated federal objectives. Section 3(e) of the National Science Foundation Act of 1950, as amended, states that "it shall be an objective of the Foundation to strengthen research and education in the sciences and engineering, including independent research by individuals, throughout the United States, and to avoid undue concentration of such research and education." Prior to this, in 1947, a Steelman report, titled "Science and Public Policy," in discussing the formation of NSF, stated "it is clear that a portion of the funds expended by the National Science Foundation should be used to strengthen the weaker, but promising, colleges and universities, and thus to increase our total scientific potential."

In 1978, Congress authorized the NSF to conduct EPSCoR in response to broad public concerns about the extent of geographical concentration of federal funding for Research and Development (R&D). Eligibility for EPSCoR participation was limited to those jurisdictions that have historically received lesser amounts of federal R&D funding and have demonstrated a commitment to develop their research bases and improve the quality of S&E research conducted at their universities and colleges.

The success of the NSF EPSCoR program during the 1980s subsequently prompted Congress to authorize the creation of EPSCoR and EPSCoR-like programs in six other federal agencies: the Departments of Energy, Defense, and Agriculture; the National Aeronautics and Space Administration; the National Institutes of Health; and the Environmental Protection Agency. In FY 1992, the EPSCoR Interagency Coordinating Committee (EICC) was established between the federal agencies with EPSCoR or EPSCoR-like programs. The major objectives of the EICC focused on improving coordination among and between the federal agencies in implementing EPSCoR or EPSCoR-like programs consistent with the policies of participating agencies. The participating agencies agreed to the following objectives:

- Coordinate federal EPSCoR and EPSCoR-like programs to maximize the impact of federal support while eliminating duplication in states receiving EPSCoR support from more than one agency.
- Coordinate agency objectives with state and institutional goals, where appropriate, to obtain continued nonfederal support of science and technology (S&T) research and training.
- Coordinate the development of criteria to assess gains in academic research quality and competitiveness and in S&T human resource development.
- Exchange information on pending legislation, agency policies, and relevant programs related to S&T research and training and, when appropriate, to provide responses on issues of common concern.

EPSCoR seeks to increase the R&D competitiveness of an eligible state through the development and utilization of the S&T resources residing in its major research universities. It strives to achieve this objective by (1) stimulating sustainable S&T infrastructure improvements at the state and institutional levels that significantly increase the ability of EPSCoR researchers to compete for federal and private sector R&D funding, and (2) accelerating the movement of EPSCoR researchers and institutions into the mainstream of federal and private sector R&D support.

In FY 2010, five EICC agencies spent a total of $460.1 million on EPSCoR and EPSCoR-like programs, up from $225.3 million in 2001 (table 5-A). The Environmental Protection Agency and the Department of Defense discontinued issuing separate EPSCoR program solicitations in FY 2006 and 2010, respectively.

Table 5-A
EPSCoR and EPSCoR-like program budgets, by agency: FY 2001–10
(Millions of dollars)

Agency	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
All agencies	225.3	288.9	358.0	353.3	367.4	367.1	363.1	418.9	437.2	460.1
DOD	18.7	15.7	15.7	8.4	11.4	11.5	9.5	17.0	14.1	0.0
DOE	7.7	7.7	11.7	7.7	7.6	7.3	7.3	14.7	16.8	21.6
EPA	2.5	2.5	2.5	2.5	2.4	0.0	0.0	0.0	0.0	0.0
NASA	10.0	10.0	10.0	10.0	12.0	12.5	12.8	15.5	20.0	25.0
NIH	100.0	160.0	210.0	214.0	222.0	220.0	218.0	223.6	224.3	228.8
NSF	74.8	79.3	88.8	93.7	93.4	97.8	101.5	120.0	133.0	147.1
USDA	11.6	13.7	19.3	17.0	18.6	18.0	14.0	28.1	29.0	37.6

DOD = Department of Defense; DOE = Department of Energy; EPA = Environmental Protection Agency; EPSCoR = Experimental Program to Stimulate Competitive Research; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = U.S. Department of Agriculture

NOTE: EPA discontinued issuing separate EPSCoR program solicitations in FY 2006.

SOURCE: Data provided by agency EPSCoR representatives; collected by NSF Office of Integrative Activities, Office of EPSCoR, April 2011.

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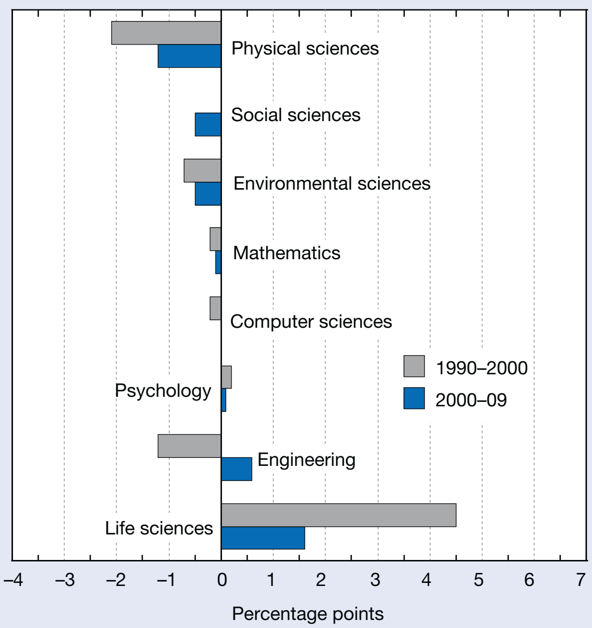
Figure 5-5
Changes in share of academic R&D, by selected S&E field: 1990–2000 and 2000–09



NOTE: Fields ranked by change in share during 2000–09, in ascending order.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges. See appendix table 5-6.

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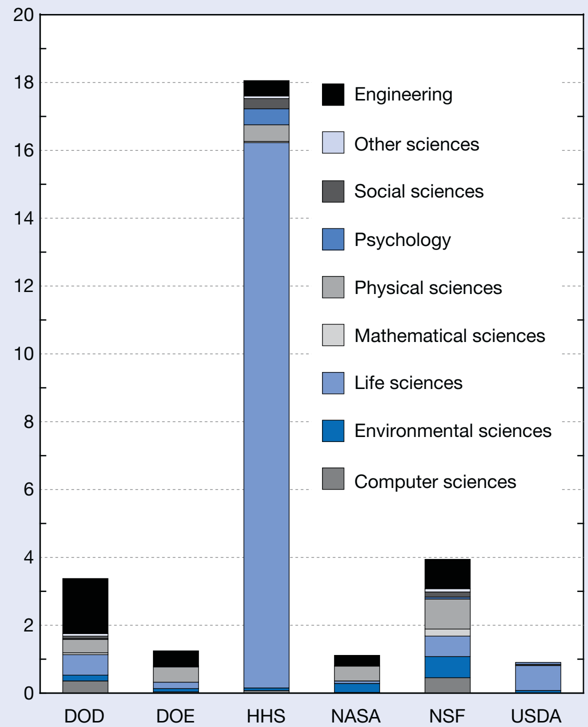
Figure 5-6
Federally financed academic R&D expenditures, by agency and S&E field: FY 2009

Current dollars (billions)



DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges (FY 2009). See appendix table 5-7.

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Non-S&E R&D

Academic institutions spent a total of $2.4 billion on R&D in non-S&E fields in FY 2009 (table 5-1), an increase of 8% over the $2.2 billion spent in 2008.[9,10] This $2.4 billion is in addition to the $54.9 billion expended on S&E R&D. The federal government funds smaller proportions of R&D in non-S&E than in S&E fields: 36% of the $2.4 billion in non-S&E R&D in FY 2009.

The largest amounts reported for R&D in non-S&E fields were for education ($921 million), business and management ($341 million), and humanities ($253 million). Other areas of non-S&E R&D include law, social work, communication, journalism, library science, and the visual and performing arts.

Academic R&D by Institution

The prior discussion examined R&D for the academic sector as a whole. This section discusses some of the differences that prevail across the types of academic institutions.

R&D Funding for Public and Private Universities and Colleges

In FY 2009, public institutions received $37.5 billion in academic S&E R&D and private institutions received $17.4 billion (appendix table 5-9).

Although public and private universities rely on the same major sources of R&D funding, the importance of the different sources varies substantially (figure 5-7). The federal government provided 71% of the R&D funding for private institutions but only 54% for public institutions. Conversely, public institutions received around 9% of their R&D funding from state and local governments, while private institutions received a little over 2%.

Public academic institutions also supported a larger portion of their R&D from their own sources—24%, compared to 12% at private institutions. This larger proportion of institutional R&D funds in public institutions may reflect the general-purpose state and local government funds that public institutions have directed toward R&D. Private institutions in turn report a larger proportion of unrecovered indirect costs (54% of their institutional total in FY 2009, versus 42% for public institutions). For both types of institutions, these unrecovered indirect costs have declined over the past decade, from 63% to 54% for private institutions and from 44% to 42% for public institutions (figure 5-8).

Both public and private institutions received approximately 6% of their R&D support from industry in FY 2009. The share of total R&D expenditures funded by all other sources was also comparable, at 7% in public and 9% in private institutions.

Distribution of R&D Funds across Academic Institutions

Academic R&D expenditures are concentrated in a relatively small number of institutions. In FY 2009, 711 institutions reported spending at least $150,000 on S&E R&D. Of these, the top-spending 20 institutions accounted for 30% of total academic R&D spending and the top 100 for 80% of this spending (figure 5-9).

Table 5-1
R&D expenditures at academic institutions in non-S&E fields: FY 2007–09
(Millions of current dollars)

Field	2007 Total expenditures	2007 Federal expenditures	2008 Total expenditures	2008 Federal expenditures	2009 Total expenditures	2009 Federal expenditures
All non-S&E fields	2,058	808	2,206	831	2,386	867
Business and management	275	54	326	66	341	68
Communication, journalism, and library science	90	31	90	29	108	30
Education	902	473	869	450	921	480
Humanities	242	60	246	56	253	60
Law	74	29	89	28	107	23
Social work	93	40	124	59	139	62
Visual and performing arts	46	4	59	4	73	4
Other non-S&E fields	335	116	404	139	445	140

NOTE: Detail may not add to total because some respondents reporting non-S&E R&D expenditures did not break out total and federal funds by non-S&E fields.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges.

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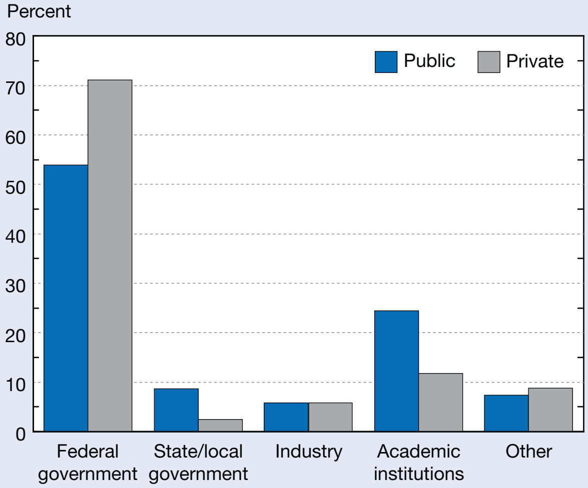
Figure 5-7
Sources of R&D funding for public and private academic institutions: FY 2009



NOTE: Science and engineering R&D; non-S&E R&D not included.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges (FY 2009). See appendix table 5-9.

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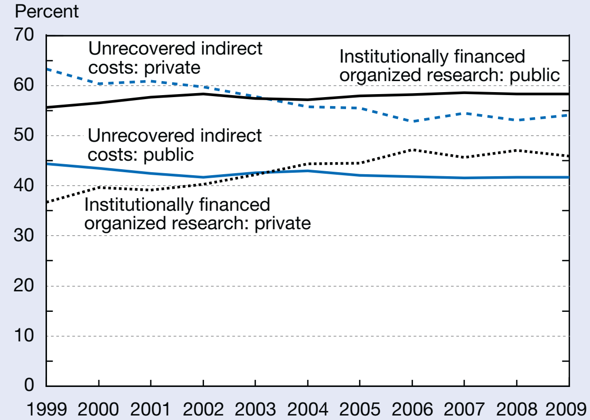
Figure 5-8
Components of institutional R&D expenditures for public and private academic institutions: 1999–2009



NOTE: Science and engineering R&D; non-S&E R&D not included.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2010) of Survey of Research and Development Expenditures at Universities and Colleges.

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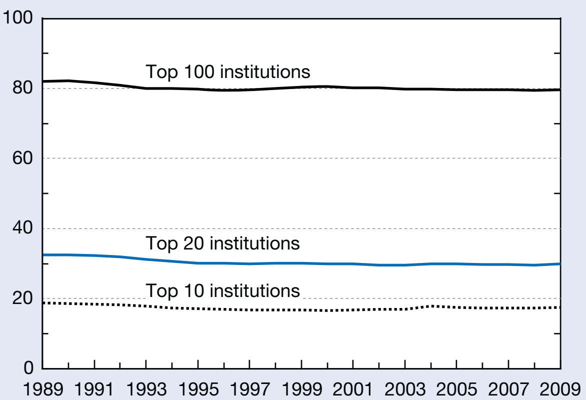
Figure 5-9
Share of academic R&D, by institution rank in R&D expenditures: FY 1989–2009



NOTE: Science and engineering R&D; non-S&E R&D not included.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2010) of Survey of Research and Development Expenditures at Universities and Colleges.

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The top 100 institutions are listed in appendix table 5-10. The concentration of academic R&D funds among the top 100 institutions has remained largely constant over the past two decades (figure 5-9). Similarly, the shares held by both the top 10 and the top 20 institutions have not changed much over the same period. (Even so, the identities of the universities in each of these groups have varied over time, as universities increase or decrease their R&D activities. For example, 5 of the top 20 institutions in FY 1988 were no longer in the top 20 in FY 2008.)

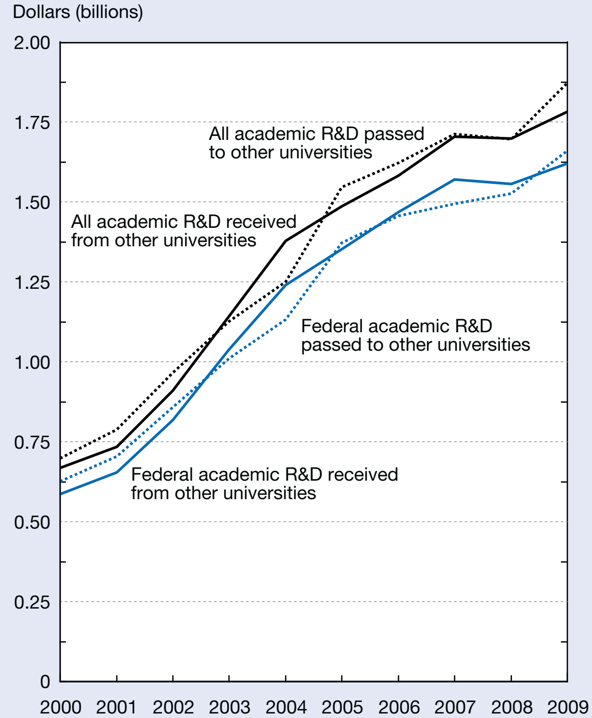
A similar concentration is found among universities that perform non-S&E R&D. The top 20 performers accounted for 36% of the total non-S&E R&D expenditures in FY 2009 (appendix table 5-11).

R&D Collaboration between Academic Institutions

A persistent trend in academic R&D has been the growth of research collaboration—notably evident in the growth of jointly authored research articles (see later in this chapter for details). This trend is also evident in flows of funds among institutions to support collaborative research activities. One indicator of this collaboration is the amount of total R&D expenditures that is passed through to other academic institutions or received by institutions as subrecipient funding.[11]

On this basis, the R&D funds for joint projects passed through universities to other university subrecipients more than doubled from FY 2000 to 2009, from $699 million to $1.9 billion (figure 5-10 and appendix table 5-12). The FY 2009 value is about 3% of total academic R&D expenditures that year, compared with 2% in 2000. In FY 2009, $1.7 billion (89%) of these pass-through funds came from federal sources.

Figure 5-10
Total and federally funded academic R&D pass-throughs: FY 2000–09



NOTE: Science and Engineering R&D; non S&E R&D not included.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges. See appendix table 5-12.

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Overall, $3.8 billion was passed through institutions to all types of subrecipients in FY 2009 (including both academic and nonacademic institutions), and $4.1 billion was received as subrecipient funding from all types of pass-through entities (appendix table 5-12). Again, the majority of these funds (85% of pass-through funds and 90% of subrecipient expenditures) were from federal sources.

Infrastructure for Academic R&D

Physical infrastructure is an essential resource for the conduct of R&D. Not long ago, the capital infrastructure for R&D consisted primarily of research space (such as laboratories and computer rooms) and instrumentation. Accordingly, the square footage of a designated research space and counts of instruments are principal indicators of the status of research infrastructure.

Over the last 20 years, however, advances in information technology have brought significant changes to both the methods of scientific research and the infrastructure needed to conduct R&D. The technologies, human interfaces, and associated processing capabilities resulting from these innovations are often included in the term *cyberinfrastructure.* Cyberinfrastructure may involve mainly one resource, such as a network used to transfer data, or it may involve a complex interaction of many resources resulting in sophisticated capabilities, such as high-performance computation or remote use of scientific instrumentation. No matter how simple or complex these technologies and their human interfaces may be, cyberinfrastructure has become an essential resource for science.

Indicators for research facilities, research equipment, and cyberinfrastructure capacity are discussed in this section. (For an overview of the sources of data used see the sidebar, "Data on the Financial and Infrastructure Resources for Academic R&D," earlier in this chapter.)

Research Facilities

Research Space

At the close of academic FY 2009, research-performing colleges and universities had 196.1 million net assignable square feet (NASF) of research space available (appendix table 5-13).[12] This was 2.2% above the assignable square footage at the end of FY 2007.

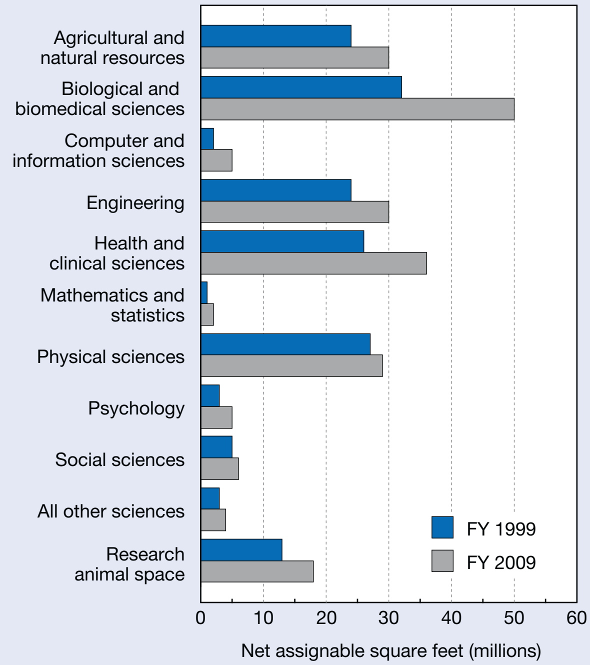
This increase represented continuity in a now two-decade long trend of academic institutions investing to expand their research space. Even so, the pace of growth has slowed in the last few years. The 2.2% expansion over the FY 2007–09 period was the slowest since the 1988–90 period. (The rate of increase peaked in 2001–03 at 11%, and has gradually declined since then.)

The S&E field of biological/biomedical sciences currently accounts for the largest portion of research space, or 50.3 million NASF in FY 2009 and 26% of the academic total (figure 5-11 and appendix table 5-13).[13] The related field of health/clinical sciences was the second largest, accounting for 36.3 million NASF and 19% of the total. Still sizable are engineering (30.2 million NASF, 15%), agricultural/natural resources (29.5 million NASF, 15%), and physical sciences (28.5 million NASF, 15%). The other fields are substantially smaller: social sciences (5.5 million NASF, 3%), computer/information sciences (5.2 million NASF, 3%), psychology (5.2 million NASF, 3%), mathematics/statistics (1.5 million NASF, 1%), and all other sciences (3.9 million NASF, 2%).

The aforementioned slowing pace of growth in overall academic research space since FY 2005 has played out in a variety of ways across the S&E fields (appendix table 5-13). The large amount of space for biological/biomedical sciences continued to expand at a substantial rate in both the FY 2005–07 and 2007–09 periods. The agricultural/natural resources field also increased its research NASF in both periods. Engineering expanded in FY 2005–07, but had no growth in the 2007–09 period.

Even so, the amount of research space available to a sizable number of S&E fields has experienced no growth or a decline since FY 2005. Health/clinical sciences and physical sciences, both fields with large amounts of research space, experienced declines in each of the FY 2005–07 and 2007–09 periods.[14] The decline in the health/clinical sciences is particularly notable, because this field exhibited some of the largest increases in research space in any S&E field in the first half of the 2000 decade. While much smaller in NASF size, the social sciences exhibited a research space decline in both FY 2005–07 and 2007–09. And, also small, the mathematics/statistics field exhibited a decline in 2007–09.

Figure 5-11
S&E research space at academic institutions, by field: FY 1999 and 2009



NOTE: S&E fields are those used in the National Center for Educational Statistcs (NCES) Classification of Instructional Programs (CIP). NCES updates the CIP every 10 years. S&E fields here reflect the NCES 2000 CIP update.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities. See appendix table 5-13.

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Compared with other fields, the computer sciences exhibited among the largest rates of increase in research space from FY 2001 to 2007 (appendix table 5-13). Nonetheless, its total research space, currently at 5.2 million NASF, is less than most fields.

New Construction

Concomitant with the slowing expansion of overall academic research space, new construction also slowed in the second half of the 2000 decade (table 5-2). The 16.2 million NASF of new construction in FY 2002–03 dropped to about 8.8 million in FY 2006–07, even if up somewhat, to 9.9 million in FY 2008–09. Similarly, within the broad decline of total research space, the amount and direction of change in new construction varied significantly across the S&E fields.

The construction starts for new research space in the biological/biomedical sciences was the largest among all the fields in FY 2006–07 and 2008–09, or 2.9 million NASF

Table 5-2
New construction of S&E research space in academic institutions, by field and time of construction: FY 2002–09

Field	Started in FY 2002 or FY 2003	Started in FY 2004 or FY 2005	Started in FY 2006 or FY 2007	Started in FY 2008 or FY 2009
	Net assignable square feet (millions)			
All fields	16.2	10.2	8.8	9.9
Agricultural and natural resources	0.8	0.4	0.5	0.4
Biological and biomedical sciences	4.0	3.2	2.9	3.5
Computer and information sciences	1.0	0.3	0.6	0.3
Engineering	2.2	1.5	1.3	2.1
Health and clinical sciences	5.0	3.3	1.7	1.9
Mathematics and statistics	*	*	*	*
Physical sciences	2.1	0.8	1.0	1.0
Earth, atmospheric, and ocean sciences	0.6	0.3	0.3	0.1
Astronomy, chemistry, and physics	1.5	0.5	0.7	0.9
Psychology	0.2	0.2	0.1	0.3
Social sciences	0.2	0.1	0.1	0.2
Other sciences	0.7	0.3	0.7	0.3
Research animal space	1.4	1.2	1.0	0.8
	Share of total new construction square feet (%)			
All fields	100.0	100.0	100.0	100.0
Agricultural and natural resources	4.9	3.9	5.7	4.0
Biological and biomedical sciences	24.7	31.4	33.0	35.4
Computer and information sciences	6.2	2.9	6.8	3.0
Engineering	13.6	14.7	14.8	21.2
Health and clinical sciences	30.9	32.4	19.3	19.2
Mathematics and statistics	*	*	*	*
Physical sciences	13.0	7.8	11.4	10.1
Earth, atmospheric, and ocean sciences	3.7	2.9	3.4	1.0
Astronomy, chemistry, and physics	9.3	4.9	8.0	9.1
Psychology	1.2	2.0	1.1	3.0
Social sciences	1.2	1.0	1.1	2.0
Other sciences	4.3	2.9	8.0	3.0
Research animal space	8.6	11.8	11.4	8.1

* = >0 but <50,000 net assignable square feet

NOTES: Detail may not add to total because of rounding. Figures for research animal space listed separately and also included in individual field totals. S&E fields are those used in the National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP). NCES updates the CIP every 10 years; S&E fields here reflect the NCES 2000 CIP update. For comparison of subfields in the FY 2005 and FY 2007 surveys, see S&E Research Facilities: FY 2007, detailed statistical tables.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

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and 3.5 million NASF, respectively. Further back were the health/clinical sciences (1.7 million NASF in FY 2006–07, 1.9 million in 2008–09) and engineering (respectively, 1.3 million and 2.1 million). All the other fields reported some new construction starts in both FY 2006–07 and 2008–09, but at levels well below the top three fields.

Academic institutions draw on various sources to fund their capital projects, including the institutions' own funds, state or local governments, and the federal government. For the construction of new research space initiated in FY 2008–09, about 62% of the funding came from institutions' internal sources, 36% from state/local government, and the remaining 3% from the federal government. This was similar to the new construction initiated in FY 2006–07, where the funding shares were, 62%, 32%, and 6%, respectively. In recent years, the federal portion of funding has been under 10% and declining, with the FY 2009 level the lowest for several decades.

Research Equipment

In FY 2009, about $2.0 billion in current funds was spent for academic research equipment (i.e., moveable items, such as computers or microscopes) necessary for the conduct of organized research projects (appendix table 5-14).[15] The corresponding totals in earlier years were $1.9 billion in FY

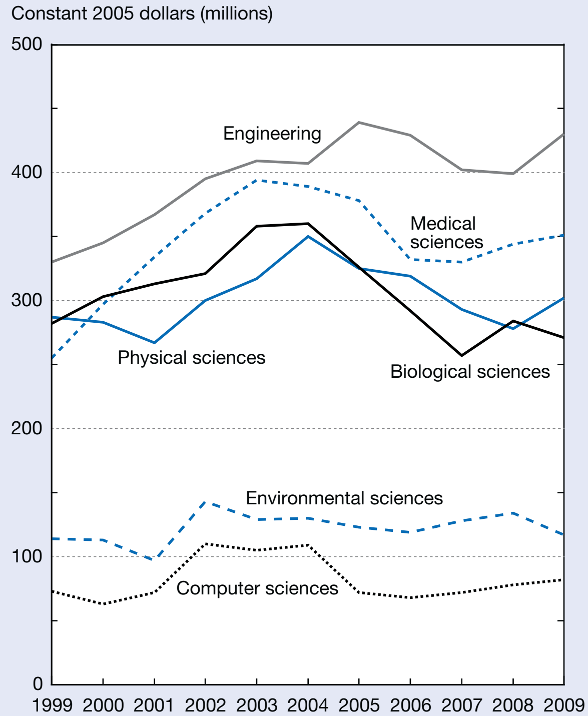
2008, $1.9 billion in FY 2004, and $1.3 billion in FY 1999. Adjusted for inflation, the change in this spending from 2008 to 2009 was a 2% increase, which was an increase of 16% over the 1999 spending level, but a 9% decline from the 2004 level.

The $2.0 billion of equipment spending in FY 2009 was just under 4% of the $54.9 billion of total academic R&D expenditures that year. In FY 2004, the share was somewhat above 4% of the academic R&D total. In FY 1999, the fraction was closer to 5%.

This equipment spending continues to be concentrated in just a few S&E fields. In FY 2009, three fields accounted for 82% of the annual total: life sciences (41%), engineering (24%), and the physical sciences (17%). The shares for these three fields have remained similarly predominant for many years (appendix table 5-14). Even so, when adjusted for inflation, the annual level of equipment spending in all three fields has declined since 2005—reversing a trend of steady growth from FY 2001 to 2004 (figure 5-12).

Some of the funding for academic research equipment comes from the federal government. These federal funds are generally received as part of research grants or as separate equipment grants. In FY 2009, the federal government supported 55% of total academic research equipment funding—a figure that has fluctuated between 55% and 63% over the last 20 years (appendix table 5-15). Nevertheless, the federal share of funding varies significantly by S&E field, ranging from 26% to 77% in 2009. In FY 2009, computer sciences had the largest proportion of federally funded R&D equipment (77%), with atmospheric sciences a close second (76%).

Figure 5-12
Current fund expenditures for S&E research equipment at academic institutions, by field: 1999–2009



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2005 dollars.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges. See appendix table 5-14.

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Cyberinfrastructure

Networking is an essential component of cyberinfrastructure. It facilitates research-related activities such as communication, data transfer, high-performance computation, and remote use of instrumentation.[16] In FY 2009, networking infrastructure on many academic campuses was pervasive and still rapidly expanding in capability and coverage. Research-performing institutions had more connections, bandwidth, and campus coverage than they did earlier in the decade.[17] (Network "bandwidth" is the amount of data that can be transmitted in a given amount of time, typically measured in bits per second.) Colleges and universities reported external network connections with greater bandwidth, faster internal network distribution speeds, more connections to high-speed networks, and greater wireless coverage on campus.

Some academic cyberinfrastructure is dedicated primarily to research activities. For example, universities may have high-performance networks (such as the National LambdaRail or networks to government agencies) available almost exclusively for research activities, and this bandwidth capacity is only for these activities. Nonetheless, universities may have other networks that are available to the entire campus community for both research and non-research activities, and this bandwidth capacity is not an indicator solely of research capacity.

Bandwidth to External Connections

Academic institutions can have multiple networking resources, at varying connection speeds. Internet1—the public multiuse, commodity network often called the "Internet"—is one such component. Many institutions also have direct or indirect connections to high-performance networks that support the development and use of advanced applications and technologies. In the academic community, these high-performance networks are chiefly Internet2 (a high performance backbone network providing leading-edge network services to member colleges, universities, and research laboratories across the country), the National LambdaRail (an advanced optical network for research and education, organized by a consortium of universities, private companies, and federal labs), and connections to federal research networks.

Early in the 2000 decade, some academic institutions reported no Internet1 connections of any kind. By mid-decade, all institutions had Internet1 connections and bandwidth speeds were increasing. Between FY 2005 and FY 2009, the fraction of institutions with total Internet1 and Internet2 bandwidth of more than 100 megabits per second increased from 52% to 80% (table 5-3). Furthermore, the share of institutions with total Internet1 and Internet2 bandwidths of 1 gigabit per second or faster rose from 22% in FY 2005 to 45% in FY 2009. (If current institutional estimates are realized, the percent of institutions with total bandwidths of 1 gigabit or faster will reach 52% in FY 2010.)

Bandwidth has increased broadly across all types of academic institutions. Nevertheless, a greater fraction of doctorate-granting institutions have the faster bandwidths. In FY 2009, 87% of the institutions that granted doctorates had total Internet1 and Internet2 bandwidth of at least 1 gigabit per second, and 32% had bandwidth greater than 2.4 gigabits. In contrast, 71% of nondoctorate granting institutions had total bandwidth at 1 gigabit per second or above and 8% above 2.4 gigabits.

Part of the increase in institutions' bandwidth can be attributed to an increase in the number of connections to high-performance networks (table 5-4). The number of connections to Internet2 has grown gradually over the current decade; by the end of FY 2009, a large majority (75%) of institutions had Internet2 connections. Between FY 2007 and 2009, the percentage of institutions with connections to the National LambdaRail increased, from 25% to 34% of all institutions. The number of institutions anticipating connections to federal government high-performance networks such as the Department of Energy's ESnet or NASA's NREN further increased in FY 2009. Institutions have also begun connecting to more than one high-performance network—for example, in FY 2009, 34% had connections to both Internet2 and the National LambdaRail.

Internal Institutional Networks

The bandwidth speeds of academic institutions' internal networks have also increased considerably. Since early in the present decade, the percentage of institutions with slower bandwidth has rapidly decreased while the percentage with faster bandwidths has rapidly increased. In FY 2003, 66% of institutions had bandwidth less than 1 gigabit per second, but by the end of FY 2009, only 19% did (table 5-5). In FY 2003, no institutions had bandwidth speeds faster than 2.5 gigabits per second, but by FY 2009, 24% of academic institutions did. By FY 2009, 82% of institutions had speeds of 1 gigabit per second or faster.

In FY 2009, all academic institutions had at least some wireless coverage in their campus buildings. In FY 2003, only 14% of these institutions had more than half of their building infrastructure covered by wireless; by FY 2009, the comparable figure was 74%.

The Academic Doctoral S&E Workforce

S&E doctorate holders in academia influence the nation's academic R&D enterprise in two key ways. They work in institutions that conduct academic R&D and produce the bulk of academic articles and patents. Moreover, they teach individuals who then go on to earn S&E doctorates, many of whom

Table 5-3
Bandwidth of commodity internet (Internet1) and Internet2 at academic institutions: FY 2005–10
(Percent distribution)

Bandwidth	FY 2005	FY 2007	FY 2009	FY 2010[a]
All bandwidth	100	100	100	100
No bandwidth	0	0	0	0
≤10 mb	6	3	1	1
11–100 mb	42	33	19	13
101–999 mb	30	31	35	34
1–2.4 gb	15	23	25	25
2.5–9 gb	4	4	5	6
10 gb	*	2	4	7
>10 gb	2	4	11	14
Other	*	0	0	0
Number of institutions	449	448	495	494

* = >0 but <0.5%

mb = megabits per second; gb = gigabits per second

[a]Figures for 2010 are estimated.

NOTES: Details may not add to 100% due to rounding. Internet1, also termed commodity internet, is the general public, multiuse network often called the "Internet." Internet2 is a high-performance backbone network that enables the development of advanced Internet applications and the deployment of leading-edge network services to member colleges, universities, and research laboratories across the country. Total bandwidth for FY 2009 and 2010 includes National LamdaRail bandwidth. The response categories in the FY 2005 survey varied slightly from those in the FY 2007 and 2009 surveys; in the FY 2005 survey, the categories were "1 to 2.5 gb" and "2.6 to 9 gb."

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

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Table 5-4
Institutions with high-performance network connections, by type of institution: FY 2005–09
(Percent)

Type of institution	Internet2	National LambdaRail	A federal government research network	State or regional high-performance network	Other
FY 2005					
All academic	68	10	11	na	12
Doctorate granting	82	11	13	na	15
Nondoctorate granting	38	7	6	na	6
Public	73	11	12	na	14
Private	58	8	9	na	9
All biomedical	24	2	1	na	3
Research institutions	19	1	1	na	3
Hospitals	35	4	2	na	2
FY 2007					
All academic	70	25	11	55	3
Doctorate granting	81	32	13	59	4
Nondoctorate granting	46	10	4	43	1
Public	75	29	12	61	3
Private	61	17	8	41	3
All biomedical	26	4	0	13	2
Research institutions	20	3	0	10	3
Hospitals	37	6	0	19	2
FY 2009					
All academic	75	34	13	60	8
Doctorate granting	87	43	17	70	9
Nondoctorate granting	51	18	6	39	5
Public	83	41	16	73	7
Private	59	22	8	36	10
All biomedical	29	10	2	15	1
Research institutions	22	11	1	16	1
Hospitals	47	8	4	14	2

na = not applicable; data were not collected in FY 2005.

NOTES: Internet2 is a high-performance hybrid optical packet network. The network was designed to provide next-generation production services as well as a platform for the development of new networking ideas and protocols. National LambdaRail (NLR) is an advanced optical network infrastructure for research and education. NLR enables cutting-edge exploration in the sciences and network research. An institution may have a connection to more than one high-performance network.

SOURCE: National Science Foundation/National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

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will work in academia and contribute to academic R&D. The focus of this section is on the research aspects of the employment of doctoral scientists and engineers in academia.

This section examines trends in the doctoral S&E academic workforce in terms of its demographic composition and its deployment across institutions, positions, and fields. Particular attention is paid to the component of the academic workforce that is more focused on research, including graduate assistants, those employed in postdoctoral positions, and researchers receiving federal support.

The discussion in this section is limited to individuals, including foreign-born individuals, who received their S&E doctorate at a U.S. institution. (More than two-thirds of foreign-born doctorate holders employed in the United States earned their doctorate degree from a U.S. institution; see chapter 3 for more information on foreign-born doctorate holders working in the United States). Owing to the complex interrelationships among faculty and nonfaculty positions that jointly produce R&D outcomes, much of the discussion addresses the overall academic employment of S&E doctorate holders, including those in nonfaculty positions. At various points the characteristics of full-time faculty are discussed.

Table 5-5
Highest internal network speeds, by highest degree granted: FY 2003–09
(Percent distribution)

Fiscal year and connection speed	All academic institutions	Highest degree granted: Doctorate	Nondoctorate
FY 2003	100	100	100
≤10 mb	2	3	2
11–999 mb	64	55	88
1–2.5 gb	33	43	10
2.6–9 gb	0	0	0
10 gb	0	0	0
>10 gb	0	0	0
Other	0	0	0
FY 2005	100	100	100
≤10 mb	0	0	1
11–999 mb	46	38	64
1–2.5 gb	50	56	35
2.6–9 gb	1	1	0
10 gb	3	4	0
>10 gb	*	*	0
Other	0	0	0
FY 2007	100	100	100
≤10 mb	1	1	1
11–999 mb	24	18	39
1–2.4 gb	61	63	55
2.5–9 gb	2	2	1
10 gb	10	13	3
>10 gb	1	2	0
Other	1	1	1
FY 2009	100	100	100
≤10 mb	1	*	1
11–999 mb	18	13	28
1–2.4 gb	58	55	63
2.5–9 gb	2	3	1
10 gb	18	24	5
>10 gb	3	4	1
Other	1	1	1

* = >0 but <0.5%

mb = megabits per second; gb = gigabits per second

NOTE: Details may not add to 100% due to rounding.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

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Trends in Academic Employment of Doctoral Scientists and Engineers

Academic employment of doctoral scientists and engineers grew over the past three decades and reached a record high of 272,800 in 2008, about the same as the employment numbers in 2006 (appendix table 5-16).[18] However, the change from 2006 was the smallest single-period increase in estimated total academic employment since at least 1973. The long-term growth rate in the number of doctoral scientists and engineers employed in the academic sector was slower than the rate of growth in the business and government sectors (table 5-6). As a result, the share of all S&E doctorate holders employed in academia dropped from 55% to 44% during the 1973–2008 period (table 5-7). In 2008, nearly half of those with recently awarded S&E doctorate degrees (that is, a degree awarded within 3 years of the survey year) were employed in academia, with 18% of recent doctorate holders employed in academic postdoc positions.[19]

Academic Employment of S&E Doctorate Holders

The academic doctoral S&E workforce includes those with a doctorate in an S&E field and employed in the following positions: full and associate professors (referred to as "senior faculty"); assistant professors and instructors (referred to as "junior faculty"); postdoctoral researchers (referred to as "postdocs"); other full-time positions such as lecturers, adjunct faculty, research associates, and administrators; and part-time positions of all kinds. Academic employment is limited to those employed in 2-year or 4-year colleges or universities.

Full-time faculty positions continue to be the norm in academic employment, but S&E doctorate holders are increasingly employed in other full-time positions, postdocs, and part-time positions (figure 5-13). The share of full-time faculty among all academic S&E doctorate holders fell from 88% in the early 1970s to 73% in 2008 (appendix table 5-16). Over the same period, the share of other full-time positions rose from 6% to 15%, the share of postdocs increased from 4% to 7%, and the share of part-time positions increased from 2% to 6% of all academic S&E doctorate holders.

Table 5-6
Average annual growth rate for employment of SEH doctorate holders, by sector: 1973–2008
(Percent)

Sector	1973–2008	1973–83	1983–93	1993–2003	2003–08
All sectors	3.3	5.4	2.5	2.0	1.8
Academia	2.4	4.1	2.0	2.0	1.0
Industry	4.6	7.9	4.1	2.7	2.9
Government	3.2	5.5	2.5	3.1	0.6
Other	2.7	5.3	0.5	–1.6	11.9

SEH = science, engineering, and health

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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The proportion of full-time faculty among S&E doctorate holders in higher education fell in all fields during 1973–2008, with the life sciences and psychology experiencing the largest relative declines. Growth in postdoc positions and other full-time positions accounted for the declining share of full-time faculty positions in the life sciences, whereas the growth in part-time and other full-time positions explained the drop in share of faculty positions in psychology (appendix table 5-16).

Over the past three decades, growth in the number of life scientists with academic employment was consistently stronger than for doctorate holders in other S&E fields (figure 5-14). Growth in academic employment slowed in the early 1990s for engineering, social sciences, physical sciences, and mathematics, but has increased since then in social sciences and mathematics (appendix table 5-16).

Table 5-7
SEH doctorate holders employed in academia, by years since doctorate: Selected years, 1973–2008
(Percent)

Years since doctorate	1973	1983	1993	2003	2008
All employed doctorate holders	54.8	48.4	45.9	45.6	43.8
≤3	55.2	48.0	50.5	53.7	49.6
4–7	55.8	44.9	47.0	47.7	48.3
≥8	54.2	49.4	45.0	44.2	42.1

SEH = science, engineering, and health

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Doctorate Recipients.

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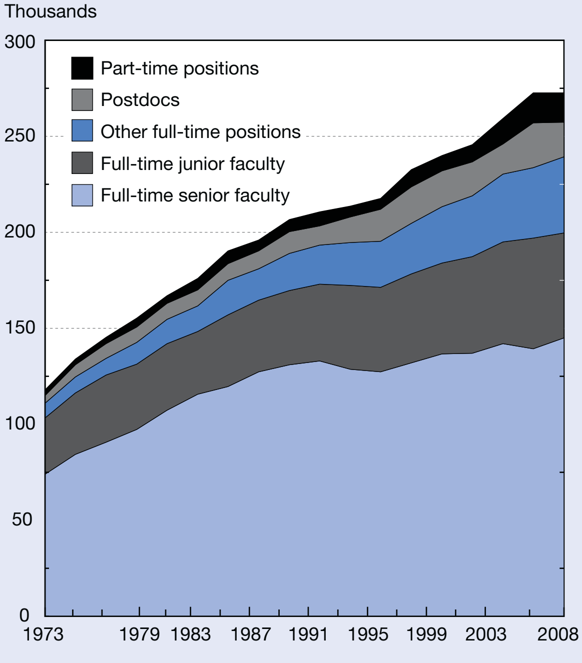
Figure 5-13
SEH doctorate holders employed in academia, by type of position: 1973–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors. Other full-time positions include positions such as research associates, adjunct appointments, lecturers, and administrative positions. Part-time positions exclude those held by students or retired persons.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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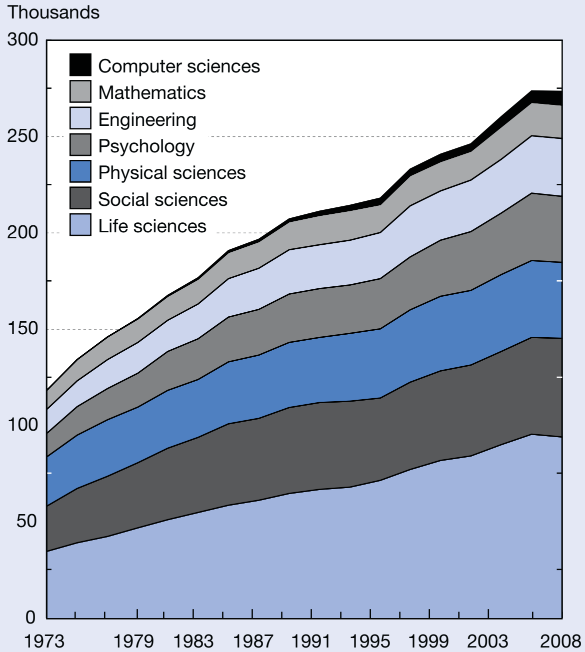
Women in Academic S&E Workforce

The number of women with S&E doctorates employed in academia grew from 10,700 in 1973 to 93,400 in 2008, more than an eightfold increase. In comparison, the number of male S&E doctorate holders increased 67% over the period, from 107,200 in 1973 to 179,400 in 2008 (appendix table 5-17).

These differential rates of increase are reflected in the steadily rising share of women in the academic S&E workforce. Women constituted 34% of all academic S&E doctoral employment and 31% of full-time faculty in 2008, up from 9% and 7%, respectively, in 1973 (table 5-8 and appendix table 5-17). Women's share of academic S&E employment increased markedly over time in all position categories, though to a lesser degree in part-time positions. Women have held a larger share of junior faculty positions (includes assistant professors and instructors) than positions at either the associate or full professor rank. However, as a result of the decades-long trend in the rising proportion of women earning doctoral degrees, coupled with their slightly greater propensity to enter academic employment, the share of women in all three faculty ranks rose significantly between 1973 and 2008. In 2008, women constituted 21% of full professors, 37% of associate professors, and 42% of junior faculty (figure 5-15).

Compared with their male counterparts in the academic doctoral S&E workforce, women were more heavily concentrated in the fields of life sciences, social sciences, and psychology, with correspondingly lower shares in engineering, the physical sciences, mathematics, and computer sciences. Women's share of doctorate holders in each of these fields grew during the 1973–2008 period (appendix table 5-17), with the most pronounced growth in share occurring in engineering, the field in which women were the least well represented.

Figure 5-14
SEH doctorate holders employed in academia, by degree field: 1973–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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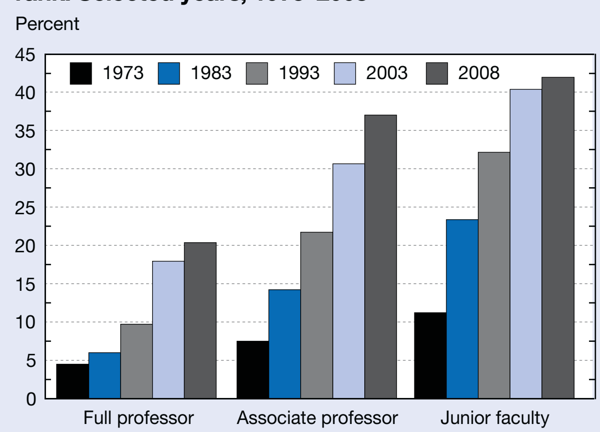
Minorities in Academic S&E Workforce

Although the number of academic S&E doctorate holders who are members of underrepresented minority groups (i.e., blacks, Hispanics, and American Indians/Alaska Natives) has increased over time, they remain a small percentage of the total (appendix table 5-18). These groups constituted about 9% of both total academic employment

Figure 5-15
Women as percentage of SEH doctorate holders with full-time employment in academia, by academic rank: Selected years, 1973–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Junior faculty includes assistant professors and instructors.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Doctorate Recipients.

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Table 5-8
Women as percentage of SEH doctorate holders employed in academia, by position: Selected years, 1973–2008
(Percent)

Position	1973	1983	1993	2003	2008
All positions	9.1	15.0	21.9	30.3	34.2
Full-time senior faculty	5.8	9.3	14.2	22.8	26.8
Full-time junior faculty	11.3	23.5	32.2	40.5	41.9
Other full-time positions	14.5	23.1	30.2	33.1	40.9
Postdocs	14.3	30.1	30.8	38.0	39.4
Part-time positions	48.3	41.7	61.0	54.5	55.2

SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors. Other full-time positions include positions such as research associates, adjunct appointments, lecturers, and administrative positions. Part-time positions exclude those employed part time who are students or retired.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Doctorate Recipients.

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and full-time faculty positions in 2008, up from 2% in 1973. Underrepresented minority groups have a relatively higher share of employment in other positions, which includes part-time positions, than in the full-time faculty and postdoc employment categories (table 5-9).

Underrepresented minorities were concentrated in different degree fields and different types of institutions than whites. Compared with white S&E doctorate holders employed in academia, underrepresented minorities were relatively concentrated in the social sciences and relatively less represented in the physical sciences and the life sciences (appendix table 5-18). Relatively fewer underrepresented minorities were employed at research universities than whites in 2008, and relatively more were employed at master's colleges and universities (table 5-10). (See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," for a brief description of the Carnegie categories.)

The share of Asians/Pacific Islanders employed in the S&E academic doctoral workforce grew dramatically over the past three decades, rising from 4% in 1973 to 14% in 2008. Asians/Pacific Islanders were heavily represented in engineering and computer sciences, where they constituted 27% and 35%, respectively, of the S&E academic doctoral workforce in 2008. Far smaller proportions of Asians/Pacific Islanders were present in social sciences (8%) and psychology (5%) (appendix table 5-18). A larger share of Asians/Pacific Islanders than whites was employed at research universities and medical schools in 2008 (table 5-10).

Table 5-9
Underrepresented minorities as percentage of SEH doctorate holders employed in academia, by position: Selected years, 1973–2008
(Percent)

Position	1973	1983	1993	2003	2008
All positions	2.0	3.7	5.0	7.9	8.9
Full-time faculty	1.9	3.6	5.0	7.8	8.7
Postdocs	2.4	4.8	4.5	7.0	8.3
Other positions	2.9	4.1	5.3	8.4	9.9

SEH = science, engineering, and health

NOTES: Underrepresented minorities include blacks, Hispanics, and American Indians/Alaska Natives. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Faculty includes full, associate, and assistant professors plus instructors. Other positions include part-time positions and full-time positions such as research associates, adjunct appointments, lecturers, and administrative positions. Other positions excludes those employed part time who are students or retired.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Doctorate Recipients.

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Table 5-10
SEH doctorate holders employed in academia, by Carnegie institution type and race/ethnicity: 2008
(Percent distribution)

Institution type	All S&E doctorate holders	Asian/Pacific Islander	White	Underrepresented minority
All institutions	100.0	100.0	100.0	100.0
Doctorate-granting, very high research	41.7	50.0	40.9	33.6
Other doctorate-granting institutions	17.8	17.1	18.0	17.8
Master's colleges and universities	18.1	13.8	18.4	22.3
Medical schools/medical centers	5.0	6.1	4.7	5.6
Baccalaureate colleges	8.1	3.3	8.9	8.4
Two-year institutions	3.6	1.8	3.8	4.6
Other	5.8	7.8	5.3	7.7

SEH = science, engineering, and health

NOTES: Underrepresented minorities include blacks, Hispanics, and American Indians/Alaska Natives. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Institutions designated by 2005 Carnegie classification code. For information on these institutional categories, see *The Carnegie Classification of Institutions of Higher Education,* http://classifications.carnegiefoundation.org/index.php.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 2008 Survey of Doctorate Recipients.

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Foreign-Born U.S. S&E Doctorate Holders

Academia has long relied on foreign-born doctorate holders, many of them with doctorate degrees from U.S. universities, to staff faculty and other academic positions. No current information is available about the number of foreign-born individuals with foreign doctorates who are employed at U.S. universities and colleges. The following discussion is limited to foreign-born individuals with U.S. doctorates.

Academic employment of foreign-born U.S. S&E doctorate holders has increased continuously since the 1970s at a rate that has exceeded the growth in academic employment of U.S.-born S&E doctorate holders (figure 5-16). As a result, the foreign-born share of the total academic employment of U.S. S&E doctorate holders increased from 12% in 1973 to nearly 25% in 2008 (figure 5-16), and reached particularly high proportions in engineering (46%) and computer sciences (51%) (appendix table 5-19). In all fields, foreign-born doctorate holders were a larger share of postdoc employment than of full-time faculty employment. Overall, 46% of postdoc positions were held by foreign-born U.S. S&E doctorate holders, compared with 23% of full-time faculty positions and 23% of other full-time positions.

Of the 39,000 Asian/Pacific Islander doctorate holders employed in academia in 2008, 9% were native-born U.S. citizens, 44% were naturalized U.S. citizens, and 47% were noncitizens. In 2008, Asians/Pacific Islanders represented 50% of the foreign-born faculty employed full-time in the United States and 62% of the foreign-born doctorate holders with postdoc appointments. In contrast, only 1% of native-born full-time faculty and 5% of native-born postdocs were Asians/Pacific Islanders.

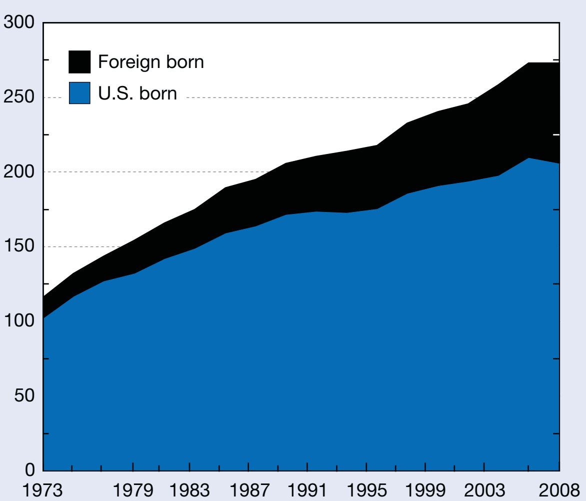
Academic Researchers

The interconnectedness of research, teaching, and public service activities in academia makes it difficult to assess the precise size and characteristics of the academic research workforce by examining the employment trends in academic positions, because individuals employed in the same position may be involved in research activities to differing degrees or not involved in research. Therefore, self-reported research involvement is a better measure than position title for gauging research activity.[20] This section limits the analysis to "academic researchers"—academic S&E doctorate holders who reported that research is either their primary work activity (that is, the activity that occupies the most hours of their work time during a typical work week) or their secondary work activity (the activity that occupies the second most work hours per week).

Doctoral S&E Researchers

From 1973 to 2008, the number of academic researchers grew from 82,300 in 1973 to 184,700 in 2008 (appendix table 5-20). The 2008 total included 137,800 individuals employed in full-time faculty positions. The proportion of academically employed S&E doctorate holders that are researchers declined slightly from 1993 (70%) to 2008 (68%) (figure 5-17). A

Figure 5-16
SEH doctorate holders employed in academia, by birthplace: 1973–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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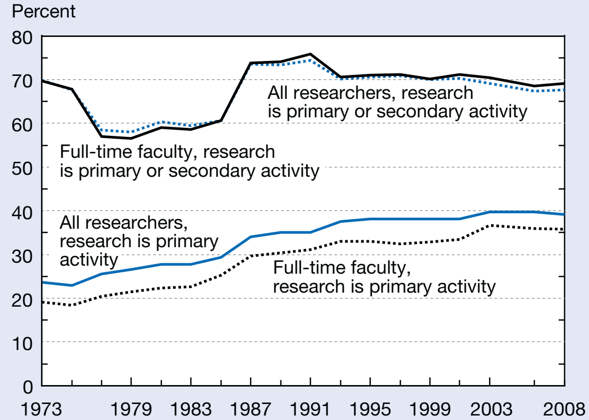
Figure 5-17
Academic researchers as percentage of SEH doctoral employment, by position and involvement in research: 1973–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Full-time faculty includes full, associate, and assistant professors plus instructors. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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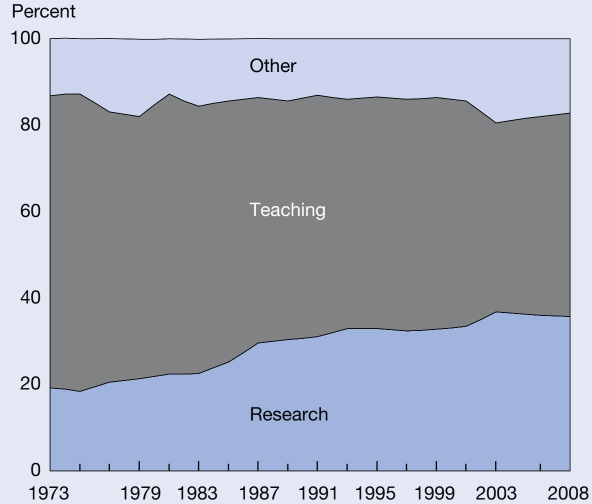
nearly identical pattern of decline was observed for the share of full-time faculty that reported research as a primary or secondary work activity. The proportions of researchers among all academic S&E doctorate holders and all full-time faculty were higher in the life sciences, engineering, and computer sciences than in the social sciences and psychology (appendix table 5-20). In most fields, the share of academic researchers declined between 1993 and 2008.

A different picture emerges when only considering researchers who report research as their primary work activity. In contrast to the declining share of academic employees who reported research as their primary *or* secondary work activity, the share who reported research as their primary work activity steadily increased from 1973 to 2008 (figure 5-17). Taken together, these trends suggest that while research as an important work activity is not becoming more widespread among S&E doctorate holders employed in academia, a growing share of academic S&E positions are becoming research intensive.

Among full-time doctoral S&E faculty, the increased share of doctorate holders reporting research as their primary work activity reflects a shift in priority from teaching to research for many faculty. From 1973 to 2008, the proportion of full-time faculty identifying research as their primary work activity climbed from 19% to 36%, while the share with teaching as their primary activity fell from 68% to 47% (figure 5-18). The balance of emphasis between teaching and research varied across the disciplines, with a higher share of faculty in the life sciences identifying research as their primary work activity, and a higher share of faculty in mathematics and social sciences reporting teaching as their primary activity. Since 1991, the proportion of doctorate holders who list research as a primary work activity declined in physical sciences, computer sciences, and life sciences fields, but grew in mathematics, psychology, engineering, and the social sciences (appendix table 5-20).

Figure 5-18
Primary work activity of full-time doctoral SEH faculty: 1973–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Full-time faculty includes full, associate, and assistant professors plus instructors. Research includes basic or applied research, development, or design.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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S&E Full-Time Faculty Researchers

Table 5-11 examines the relationship between research and the career stage of S&E full-time faculty. The smallest share of primary researchers occurred among the most recently degreed faculty (33%). The share of faculty who indicated research as their primary work activity increased

Table 5-11
SEH faculty reporting research as primary work activity, by years since doctorate and degree field: 2008
(Percent)

Years since doctorate	All fields	Physical sciences	Mathematics and statistics	Computer and information sciences	Life sciences	Psychology	Social sciences	Engineering
All years since doctorate	35.8	33.4	30.8	37.2	42.7	33.7	27.7	38.8
1–3	33.2	22.8	32.6	44.2	27.5	30.6	29.5	58.7
4–7	48.3	32.3	59.6	56.0	53.1	37.8	41.0	71.0
8–11	40.8	35.1	33.5	38.5	49.3	36.8	31.0	46.8
≥12	34.5	34.3	27.6	35.3	42.5	34.4	25.7	31.6

SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Faculty includes full, associate, and assistant professors plus instructors. Research includes basic or applied research, development, and design. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 2008 Survey of Doctorate Recipients.

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with time since doctorate in the succeeding two cohorts, and then fell in the last reported cohort (12 years or more since doctorate). The higher share (48%) of primary researchers within the second cohort, 4 to 7 years since doctorate, coincides with the period during which many early career faculty would be preparing to apply for tenure at their university, and would have heightened motivation to complete research projects and publish results. In the last cohort reported in the table, 12 years or more beyond the doctorate, the share of full-time faculty reporting research as a primary activity fell to 35%. Other responsibilities—such as mentoring younger faculty, advising doctoral students, and accepting major committee assignments or faculty leadership roles—may become primary work activities for many faculty at this career stage.

A similar pattern prevailed in most degree fields—the share of faculty who indicated that research was their primary work activity increased through the early career cohorts and then fell as faculty approached mid-career. Research was more frequently a primary work activity for early career faculty in engineering and computer sciences than for faculty in other fields (table 5-11).

Collaborative Research

Research in many fields has increasingly involved collaboration. This section describes S&E doctorate holders' self-reports of their collaboration with others using data from the 2006 Survey of Doctorate Recipients.[21] Information on trends in coauthorship can be found later in this chapter under "Coauthorship and Collaboration."

In 2006, roughly 70% of S&E full-time research faculty employed in academic institutions reported working with an immediate work team or with others working elsewhere in the same organization, nearly 60% worked with individuals in other organizations in the United States, and nearly one-third worked with individuals located in other countries. Team work is most common among life scientists, physical scientists, and engineers, and least common among mathematicians and social scientists.

International collaboration was more common among foreign-born S&E full-time research faculty. Communication by e-mail or telephone was, by far, the most commonly used mode of international collaboration, followed by travel to the United States by the foreign collaborator(s), foreign travel by the U.S.-based collaborator, and communication through web-based or virtual technology.

For a more extensive discussion of these topics, see the "Collaborative Research" section in chapter 5 of the 2010 edition of *Indicators* (NSB 2010). For data on international collaborative activity in the S&E workforce more generally, see the "International Engagement by the Domestic S&E Workforce" in chapter 3.

Graduate Research Assistants

The close coupling of advanced training with hands-on research experience is a key strength of U.S. graduate education. Many of the 434,100 full-time S&E graduate students in 2008 (table 5-12) contributed significantly to the conduct of academic research.

The number of research assistants (RAs)—full-time graduate students whose primary mechanism of financial support is a research assistantship—has grown faster than graduate enrollment, both overall and in most fields. Graduate research assistantships were the primary means of support for 27% of graduate students in 2008, up from 22% in 1973. In the field distribution of RAs, there was a shift away from the physical sciences and social sciences and into the life sciences, computer sciences, and engineering. In engineering and the physical sciences in 2008, the proportion of RAs was high relative to graduate enrollment; 42% of graduate students in the physical sciences and 40% of engineering graduate students were supported in their graduate study primarily by research assistantships. In the life sciences, the proportion of RAs relative to graduate enrollment was similar to the overall proportion across all fields (27%), possibly reflecting the heavier reliance on postdoctoral researchers rather than RAs in the life sciences fields (table 5-12).

The majority of the academic research workforce remains employed in the intensive and very intensive research universities, although the research universities' shares of both academic researchers and of RAs have declined since 1973. (See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," for a brief description of the Carnegie categories.) During the 2003–2008 period, the research universities employed 48% of all S&E doctorate holders in academic positions, 57% of those reporting research as their primary or secondary activity, and 79% of S&E graduate students for whom an RA was their primary means of support (table 5-13). Trends indicate a growing research presence by full-time academic researchers at institutions not classified as research universities, although RAs remain highly concentrated in the research universities.

Academic Employment in Postdoc Positions

The number of S&E doctorate holders employed in academic postdoc positions climbed from 4,000 in 1973 to 18,000 in 2008 (appendix table 5-16).[22] (See sidebar, "Postdoctoral Researchers.") During that time period, the share of postdocs increased from 4% to 7% of all academically employed S&E doctorate holders. Postdocs were much more prevalent in the life sciences, engineering, and the physical sciences than in social sciences, although the proportion of postdoc positions in physical sciences has declined since the mid-1990s (figure 5-19 and appendix table 5-16).

The demographic profile of individuals employed in academic postdoc positions has changed dramatically over time. The proportions of postdocs held by women, racial/ethnic minorities, and foreign-born individuals has climbed since 1973 (table 5-14).

Table 5-12
Full-time SEH graduate students and graduate research assistants at universities and colleges, by degree field: Selected years, 1973–2008

Group and degree field	1973 Thousands	1973 Percent	1983 Thousands	1983 Percent	1993 Thousands	1993 Percent	2003 Thousands	2003 Percent	2008 Thousands	2008 Percent
Graduate students	161.6	100	252.0	100	329.6	100	398.0	100	434.1	100
Physical sciences	28.9	18	37.2	15	41.9	13	41.9	11	44.5	10
Mathematics	10.3	6	11.0	4	14.5	4	14.6	4	16.2	4
Computer sciences	2.9	2	10.6	4	17.4	5	30.9	8	31.3	7
Life sciences	40.6	25	69.2	28	91.6	28	123.2	31	138.8	32
Psychology	15.2	9	26.6	11	34.8	11	35.8	9	42.1	10
Social sciences	32.4	20	43.5	17	55.6	17	61.3	15	68.2	16
Engineering	31.3	19	53.9	21	73.8	22	90.4	23	93.0	21
Graduate research assistants	35.9	100	54.9	100	90.2	100	114.3	100	118.3	100
Physical sciences	8.9	25	12.6	23	17	19	18.1	16	18.7	16
Mathematics	0.7	2	0.8	2	1.4	2	1.8	2	1.9	2
Computer sciences	0.7	2	1.4	3	3.8	4	7.5	7	7.3	6
Life sciences	9.4	26	16.5	30	28.0	31	35.5	31	37.4	32
Psychology	1.9	5	3.0	5	4.6	5	5.6	5	6.1	5
Social sciences	4.0	11	5.0	9	7.4	8	8.4	7	8.1	7
Engineering	10.4	29	15.6	28	28.0	31	37.4	33	37.0	31

SEH = science, engineering, and health

NOTES: Detail may not add to total because of rounding. Graduate research assistants are full-time graduate students with research assistantships as primary mechanism of support. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Graduate Students and Postdoctorates in Science and Engineering.

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Early Career Postdocs

A temporary postdoc appointment is a common stop along the career path of S&E doctorate holders, particularly during their early career stages. In 2008, 36% of recently degreed S&E doctorate holders in academia were employed in postdoc positions, a figure that approached the share (42%) employed in full-time faculty positions (appendix table 5-21). With the exception of 2003, the share of recently degreed S&E doctorate holders in academic postdoc positions has exceeded the share holding full-time tenured or tenure-track faculty positions since 1995 (figure 5-20). S&E doctorate holders 4 to 7 years beyond the doctorate degree were far less likely than their recently degreed counterparts to be employed in academic postdoc positions; in 2008, only 11% of these doctorate holders held postdoc positions.

The vast majority of academic postdocs are employed at very high research activity universities. In 2008, the share of all academic postdocs employed at these institutions reached 75% (table 5-15). At the research universities, 70% of S&E postdoc appointments in 2008 were held by recently degreed individuals, and 5% by doctorate holders who were 8 or more years past their degree. The postdoc populations employed at medical schools and other universities and colleges included a larger pool of doctorate holders who had not recently earned the doctorate degree.

In comparison to 1995, a larger share of S&E doctorate holders employed in academia in 2006, 45% versus 41%, had held a postdoc appointment at some point in their career, and a slightly larger share than in 1995 had been employed in postdoc positions two or more times (table 5-16). Postdocs and multiple postdocs are relatively more prevalent among early career S&E doctorate holders than among the total pool of S&E doctorate holders. Early career postdoc employment and multiple instances of postdoc employment are typical for academic careers in the life sciences and the physical sciences (table 5-16), the two fields of study that have had the highest incidence of postdocs over the years (figure 5-19).

Government Support of Academic Doctoral Researchers

The federal government provides academic researchers with a substantial portion of overall research support. This section presents data from S&E doctorate holders in academia who reported on the presence or absence (but not magnitude) of federal support for their work.[23]

Academic Scientists and Engineers Who Receive Federal Support

In 2008, 45% of all S&E doctorate holders in academia and 56% of those for whom research was a primary or secondary activity reported federal government support for their work (appendix table 5-22). For S&E as a whole and for many fields, the share of S&E doctorate holders and researchers receiving federal support has declined since the early 1990s.

Faculty and other full-time S&E doctoral employees were less likely than postdocs to receive federal support. Throughout the 1973–2008 period, fewer than half of full-time S&E faculty received federal support, whereas the share of postdocs receiving federal support was above 70%.

Table 5-13
SEH doctorate holders and graduate research assistants employed in academia, by Carnegie institution type: 1973–2008
(Percent distribution)

Group and institution type	1973–83	1983–93	1993–2003	2003–08
All employed S&E doctorate holders	100.0	100.0	100.0	100.0
Research universities	53.7	53.4	50.0	48.4
Doctorate-granting institutions	11.5	11.4	11.0	10.5
Comprehensive institutions	18.0	18.5	18.3	18.6
Other institutions	16.8	16.8	20.7	22.6
Researchers	100.0	100.0	100.0	100.0
Research universities	64.8	62.2	57.8	56.8
Doctorate-granting institutions	10.9	11.2	11.3	10.8
Comprehensive institutions	12.4	13.9	14.5	15.1
Other institutions	11.9	12.8	16.4	17.3
Graduate research assistants	100.0	100.0	100.0	100.0
Research universities	87.5	84.0	80.4	79.3
Doctorate-granting institutions	9.3	10.1	11.8	11.8
Comprehensive institutions	2.2	3.5	4.9	5.4
Other institutions	1.0	2.4	2.9	4.5

SEH = science, engineering, and health

NOTES: Detail may not add to total because of rounding. Academic employment of S&E doctorate holders limited to those employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Researchers are S&E doctorate holders employed in academia reporting research as a primary or secondary work activity; research includes basic or applied research, development, and design. Graduate research assistants are full-time graduate students with research assistantships as primary mechanism of support. Institutions designated by 1994 Carnegie classification code. Freestanding schools of engineering and technology included under comprehensive institutions. Other instititions includes freestanding medical schools, 4-year colleges, specialized institutions, and institutions without Carnegie code. For information on these institutional categories, see *The Carnegie Classification of Institutions of Higher Education*, http://classifications.carnegiefoundation.org/index.php.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients and Survey of Graduate Students and Postdoctorates in Science and Engineering.

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Postdoctoral Researchers

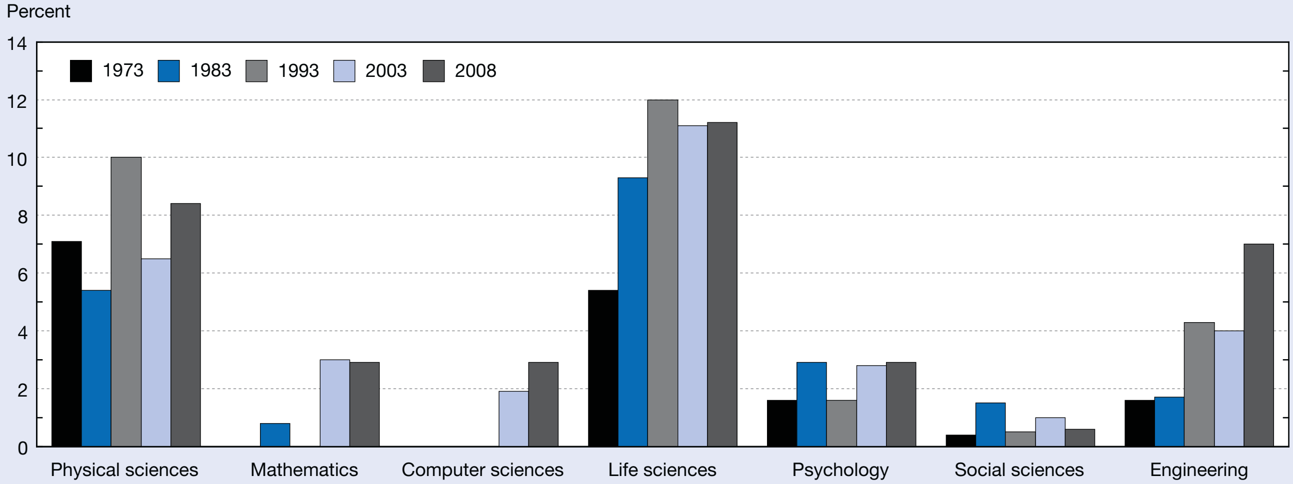
A postdoc is a temporary position in academia, industry, a nonprofit organization, or government, taken after the completion of a doctorate. It serves as a period of apprenticeship for the purpose of gaining scientific, technical, and professional skills. Ideally, the individual employed in a postdoc position gains these skills under the guidance of an advisor, and with the administrative and infrastructural support of a host institution and the financial support of a funding organization. However, the conditions of postdoc employment vary widely between academic and non-academic settings, across disciplines, and even within institutions, and formal job titles are an unreliable guide to actual work roles.

Postdoctoral researchers have become indispensable to the science and engineering enterprise and perform a substantial portion of the nation's research. Most have recently earned the doctorate degree, and so they bring a new set of techniques and perspectives that broadens their research teams' experience and makes them more competitive for additional research funding. In addition to conducting research, postdoctoral researchers also educate, train, and supervise junior members, help write grant proposals and papers, and present research results at professional society meetings (COSEPUP 2000).

Since 1991, the share of academic S&E doctorate holders receiving federal support has declined in all position categories (appendix table 5-22).

Federal support is more prevalent in very high research activity universities and medical schools. More than 60% of S&E doctorate holders and full-time faculty employed in research universities and medical schools received federal support in 2008 (appendix table 5-23). The percentage with federal support was less than 30% among those employed in doctoral/research universities, master's-granting universities, and baccalaureate colleges.

Figure 5-19
SEH doctorate holders with academic employment in postdoc position, by degree field: Selected years, 1973–2008



SEH = science, engineering, and health

NOTES: Data on computer sciences not available for 1973. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.
SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Doctorate Recipients.

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Table 5-14
SEH doctorate holders with academic employment in postdoc position, by demographic group: Selected years, 1973–2008
(Percent distribution)

Demographic group	1973	1983	1993	2003	2008
Sex					
Female	16.7	30.1	30.8	37.6	39.4
Male	83.3	69.9	69.2	62.4	60.6
Race/ethnicity					
White	85.7	81.9	68.4	63.1	57.8
Asian/Pacific Islander	11.9	13.3	27.1	30.6	33.9
Underrepresented minority	2.4	4.8	4.5	7.0	8.3
Place of birth					
United States	82.5	81.7	60.9	57.0	53.9
Foreign	17.5	18.3	39.1	43.0	46.1

SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Underrepresented minorities include blacks, Hispanics, and American Indians/Alaska Natives. Asian/Pacific Islander includes Pacific Islanders through 1999 but excludes them in 2001–08.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973, 1983, 1993, 2003, and 2008 Surveys of Doctorate Recipients.

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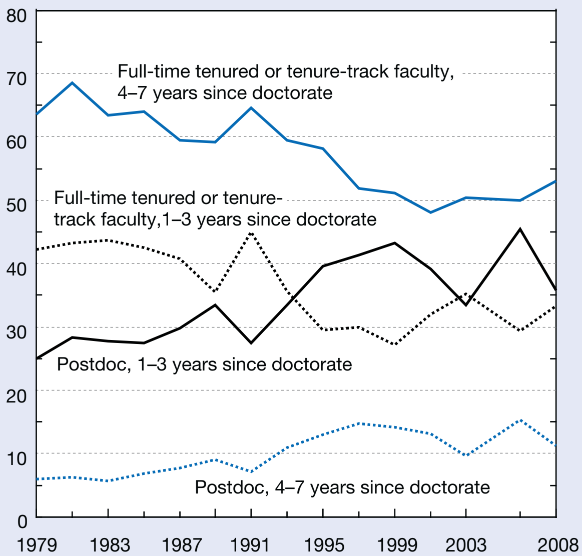
Figure 5-20
Recent SEH doctorate holders employed in academia, by position and years since doctorate: 1979–2008



SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Full-time tenured or tenure-track faculty includes full, associate, and assistant professors plus instructors.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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Federal Support of Early Career S&E Doctorate Holders

Federal support has been less available to early career S&E doctoral faculty than to more established faculty, and the percentage of early career S&E faculty with federal support has declined. From 1973–2008, S&E doctorate holders with recently earned doctorates (i.e., doctorates earned within 3 years of the survey) employed in full-time faculty positions were far less likely to receive federal support than those in postdoc positions (figure 5-21). In 2008, 27% of recent doctorate recipients in full-time faculty positions received federal support, down from 38% in 1991. Of recent S&E doctorate recipients employed in postdoc positions in 2008, 71% received federal support, which was a substantial decline from 1991 (84%).

S&E doctorate holders employed as full-time faculty who had received their doctorate 4–7 years earlier were more likely to receive federal support than those with more recently earned doctorates, and the same was true of those employed in postdoc positions (figure 5-21). As with recent doctorate recipients, the share of full-time faculty and postdocs 4–7 years beyond the doctorate who received federal support also declined from 1991. The shares of early career full-time faculty and postdocs with federal support were higher in some fields (life sciences, physical sciences, and engineering) than in others (mathematics and social sciences) (appendix table 5-24).

Table 5-15
SEH doctorate holders with academic employment in postdoc position, by Carnegie institution type and years since doctorate: 2008
(Percent distribution)

Institution type	Number of postdocs (thousands)	Total	Years since doctorate 1–3	4–7	≥8
All institutions	18.0	100.0	68.6	25.6	5.8
Doctorate-granting, very high research	13.5	100.0	69.7	25.2	5.1
Other doctorate-granting institutions	1.4	100.0	75.1	24.7	S
Medical schools/medical centers	1.6	100.0	60.4	29.0	10.7
Other universities and colleges	1.5	100.0	61.5	26.3	12.2

S = data suppressed for reasons of confidentiality and/or reliability

SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Institutions designated by 2005 Carnegie classification code. For information on these institutional categories, see *The Carnegie Classification of Institutions of Higher Education,* http://classifications.carnegiefoundation.org/index.php.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 2008 Survey of Doctorate Recipients.

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Table 5-16
SEH doctorate holders employed in academia, by years since doctorate, number of postdoc positions held during career, and degree field: 1995 and 2006
(Percent distribution)

	All fields		Life sciences		Physical sciences	
Years since doctorate and postdocs *(n)*	1995	2006	1995	2006	1995	2006
All years since doctorate	100.0	100.0	100.0	100.0	100.0	100.0
0	59.3	54.7	36.1	36.6	37.5	35.7
1	29.2	33.2	45.9	43.6	43.7	47.2
≥2	11.4	12.1	15.5	19.9	18.9	17.1
1–3 years since doctorate	100.0	100.0	100.0	100.0	100.0	100.0
0	47.1	42.7	33.7	31.9	21.0	24.2
1	44.0	49.8	54.3	57.2	63.9	69.5
≥2	8.9	7.5	12.0	10.8	15.1	6.2
4–7 years since doctorate	100.0	100.0	100.0	100.0	100.0	100.0
0	54.5	52.6	20.5	26.1	22.6	32.5
1	30.9	35.6	46.0	52.5	50.0	47.3
≥2	14.6	11.8	17.5	31.3	27.5	20.1

SEH = science, engineering, and health

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences. The number of postdoc positions held during career includes postdoc appointments outside academia.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1995 and 2006 Surveys of Doctorate Recipients.

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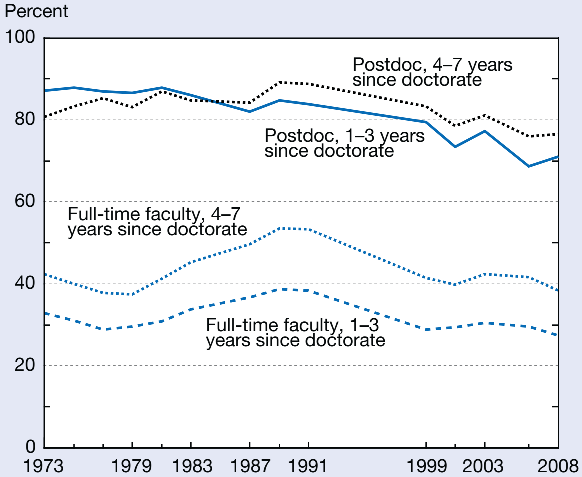
Figure 5-21
SEH doctorate holders employed in academia with federal support, by position and years since doctorate: 1973–2008



SEH = science, engineering, and health

NOTES: 1985 and 1993–97 data not comparable with other years and understate degree of federal support. In 1985 and 1993–97, federal support question asks whether work performed during week of April 15 was supported by government; in other years, question pertains to work conducted over course of entire year. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Faculty includes full, associate, and assistant professors plus instructors.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2011) of 1973–2008 Surveys of Doctorate Recipients.

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Outputs of S&E Research: Articles and Patents

Chapter 2 of this volume discusses the human capital outputs of higher education in S&E. This section continues that theme by examining the intellectual output of academic S&E research using indicators derived from published research articles and U.S. patent and related data.

Researchers have traditionally published the results of their work in the world's peer-reviewed S&E journals.[24] Article-level data from these journals are indicators of S&E research output by countries and—within the United States—by academia and other sectors of the economy.[25] (See sidebar "Bibliometric Data and Terminology.") These *bibliometric* data can also be used to track trends in S&E research collaboration, using measures of coauthorship between and among departments, institutions, sectors, and countries. Finally, citations in more current research articles to previous research, and in patents to published research articles, offer insight into the importance and impact of previous research and its connection to inventions.

S&E Article Output

Between 1999 and 2009, the total world S&E article output in the SCI/SSCI database grew at an average annual rate of 2.6% (table 5-17). Leading this growth was China at 16.8% per year, which propelled it from ninth largest S&E article producer[26] in 1999 to second largest in 2009 behind the United States. Very rapid growth of over 10% per year

Bibliometric Data and Terminology

The article counts, coauthorships, and citations discussed in this section are derived from S&E articles, notes, and reviews published in a set of scientific and technical journals tracked by Thomson Scientific in the Science Citation Index and Social Sciences Citation Index (http://www.thomsonreuters.com/business_units/scientific/). Journal items excluded are letters to the editor, news stories, editorials, and other material whose purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

Journal selection. This section uses a changing set of journals that reflects the current mix of journals and articles in the world. Thomson Reuters selects journals each year as described at http://www.thomsonreuters.com/products_services/science/free/essays/journal_selection_process/, and the selected journals become part of the SCI and SSCI. The journals selected are notable for their relatively high citation rank within their corresponding S&E subfields; journals of only regional interest are excluded.

The number of journals analyzed by NSF from SCI/SSCI was 4,093 in 1988 and 5,085 in 2010, an annual growth rate of about 1.0%. These journals give good coverage of a core set of internationally recognized peer-reviewed scientific journals. The coverage extends to electronic-only journals and print journals with electronic versions. In the period 1988–2010, the database contained 14.6 million S&E articles, notes, and reviews. Over the same period, the average number of articles, notes, and reviews per journal per year increased from about 115 to 154, an annual growth rate of about 1.3%.

Article data. Except where noted, *author* means *departmental or institutional author.* Articles are attributed to countries or sectors by the country or sector of the institutional address(es) given in the articles, *not by the national origins or the citizenship of the authoring scientists or engineers.* If no institutional affiliation is listed, the article is excluded from the counts in this chapter.

Likewise, *coauthorship* refers to *institutional* coauthorship. An article is considered coauthored only if it shows different institutional affiliations or different departments of the same institution; multiple listings of the same department of an institution are considered one institutional author. The same logic applies to cross-sector and international collaboration.

Two methods of counting articles are used: fractional and whole counts. *Fractional counting* is used for article and citation counts. In fractional counting, credit for co-authored articles is divided among the collaborating institutions or countries based on the proportion of their participating departments or institutions. *Whole counting* is used for coauthorship data. In whole counting, each institution or country receives one credit for its participation in the article. (If authors list more than one departmental or institutional affiliation, these are fractionalized for article and citation counts; whole counts are used for each affiliation in coauthorship data.)

Data in the first section *only* (“S&E Article Output”) are reported by publication year through 2009 as reported in the data files through late January, 2011. These data are noted as “by year of publication.” Publication data in the remaining bibliometrics sections (“Coauthorship and Collaboration,” “Trends in Output and Collaboration Among U.S. Sectors,” and “Trends in Citation of S&E Articles”) are reported through 2010. These data are noted as “by data file year.”

The country/economy breakouts are reported in appendix table 5-25. Data reported in this section are grouped into 13 broad S&E fields and 125 subfields (appendix table 5-26).

was also experienced by South Korea and, from low bases, by Iran, Tunisia, Thailand, Pakistan, and Malaysia.

Viewed regionally, growth in S&E article output over the decade has been uneven. Mature economies had modest growth or decline: the United States averaged 1.0%, EU member countries 1.4%, while Japan declined by –1.1% per year and Russia by –2.0%. Developing economies, mainly in Asia, far outpaced this growth in S&E articles, where China (16.8%) and South Korea (10.1%) were joined by Taiwan at 7.7%, Singapore at 8.2%, and India at 6.9% (table 5-17 and appendix table 5-27).

The research portfolios of the U.S., EU, and Asian economies differ in important ways (NSB 2010; and appendix tables 5-27 through 5-40):

- China and Japan emphasize the physical sciences more than the United States and European Union;
- The United States, European Union, and Japan produce relatively more articles in the life sciences than China or other Asian nations; and
- S&E research publications with authors in Asian countries are more heavily concentrated in engineering than those with authors in the United States or European Union.

Countries in Central and South America together increased their S&E article output between 1999 and 2009 at an annual rate of 5.6%. Brazil had the highest growth rate in the region, at 7.7% (table 5-17 and appendix table 5-27).

The countries or other entities with indexed S&E articles are always evolving.[27] In the current volume, 199 receive credit for publishing S&E articles (appendix table 5-25). Of these, a small number account for most of the publications.[28] Table 5-17 shows that five countries (the United States, China, Japan, the United Kingdom, and Germany)

Table 5-17
S&E articles in all fields, by country/economy: 1999 and 2009

Rank	Country	1999	2009	Average annual change (%)	2009 world total (%)	2009 cumulative world total (%)
–	World	610,203	788,347	2.6	na	na
1	United States	188,004	208,601	1.0	26.5	26.5
2	China	15,715	74,019	16.8	9.4	35.8
3	Japan	55,274	49,627	-1.1	6.3	42.1
4	United Kingdom	46,788	45,649	-0.2	5.8	47.9
5	Germany	42,963	45,003	0.5	5.7	53.6
6	France	31,345	31,748	0.1	4.0	57.7
7	Canada	22,125	29,017	2.7	3.7	61.4
8	Italy	20,327	26,755	2.8	3.4	64.7
9	South Korea	8,478	22,271	10.1	2.8	67.6
10	Spain	14,514	21,543	4.0	2.7	70.3
11	India	10,190	19,917	6.9	2.5	72.8
12	Australia	14,341	18,923	2.8	2.4	75.2
13	Netherlands	12,168	14,866	2.0	1.9	77.1
14	Russia	17,145	14,016	-2.0	1.8	78.9
15	Taiwan	6,643	14,000	7.7	1.8	80.7
16	Brazil	5,859	12,306	7.7	1.6	82.2
17	Sweden	9,890	9,478	-0.4	1.2	83.4
18	Switzerland	8,195	9,469	1.5	1.2	84.6
19	Turkey	3,223	8,301	9.9	1.1	85.7
20	Poland	5,100	7,355	3.7	0.9	86.6
21	Belgium	5,713	7,218	2.4	0.9	87.5
22	Iran	665	6,313	25.2	0.8	88.3
23	Israel	5,929	6,304	0.6	0.8	89.1
24	Denmark	4,783	5,306	1.0	0.7	89.8
25	Finland	4,719	4,949	0.5	0.6	90.4
26	Greece	2,626	4,881	6.4	0.6	91.1
27	Austria	4,158	4,832	1.5	0.6	91.7
28	Norway	3,043	4,440	3.9	0.6	92.2
29	Singapore	1,897	4,187	8.2	0.5	92.8
30	Portugal	1,711	4,157	9.3	0.5	93.3
31	Mexico	2,884	4,128	3.7	0.5	93.8
32	Czech Republic	2,360	3,946	5.3	0.5	94.3
33	Argentina	2,636	3,655	3.3	0.5	94.8
34	New Zealand	2,915	3,188	0.9	0.4	95.2
35	South Africa	2,303	2,864	2.2	0.4	95.5
36	Ireland	1,459	2,798	6.7	0.4	95.9
37	Hungary	2,200	2,397	0.9	0.3	96.2
38	Egypt	1,293	2,247	5.7	0.3	96.5
39	Thailand	549	2,033	14.0	0.3	96.7
40	Chile	1,059	1,868	5.8	0.2	97.0
41	Ukraine	2,355	1,639	-3.6	0.2	97.2
42	Romania	917	1,367	4.1	0.2	97.4
43	Malaysia	471	1,351	11.1	0.2	97.5
44	Slovenia	708	1,234	5.7	0.2	97.7
45	Serbia	NA	1,173	NA	0.1	97.8
46	Croatia	647	1,164	6.0	0.1	98.0
47	Pakistan	296	1,043	13.4	0.1	98.1
48	Tunisia	257	1,022	14.8	0.1	98.3
49	Slovakia	979	1,000	0.2	0.1	98.4

na = not applicable; NA = not available

NOTES: Countries/economies shown produced 1,000 articles or more in 2009. Countries/economies ranked on 2009 total. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Detail does not add to total because of countries/economies not shown.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-27.

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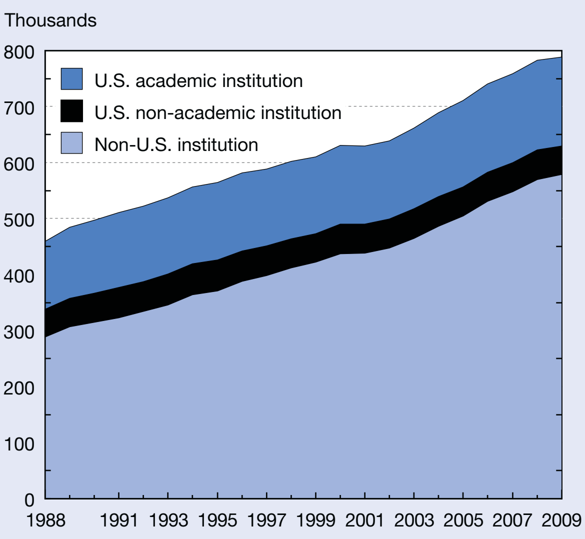
accounted for more than 50% of the total world S&E article output in 2009. The 49 countries in table 5-17—one quarter of the countries in the data—produced 98% of the world total of S&E articles.

The number of journals covered by SCI/SSCI has expanded to accommodate the rising number of research articles. Most of the increase reflects activity in new S&T centers. Figure 5-22 shows how the number of published articles has grown over the past 20 years, from 485,000 articles in 1989 to 788,000 in 2009. Non-U.S. articles have increasingly dominated world S&E article output, growing from 63% to 74% of the total. The expansion of non-U.S. S&E articles signals the return on decades of increased investments in higher education and the more recent conviction that R&D is essential to economic growth and competitiveness. It also reflects a slowdown in the growth of U.S. S&E article output to around 1% or less in recent years.

In Figure 5-22, co-authored articles are pro-rated to U.S. sectors and foreign countries, depending on their fraction of the institutional addresses. These fractions were then re-summed to produce the shares shown in the figure. But that method of allocating credit for S&E article authorship does not show the relationships among the authors, author sectors, and country authors that together illuminate the extent to which S&E research is an increasingly global, collaborative undertaking. The following sections explore these growing collaborative and international dimensions of world S&E research as indicated by data on S&E publications. Together these indicators will describe a growing globalization of the social system of scientific knowledge production and the global use of its outputs.

Figure 5-22
World S&E articles, by author characteristic: 1988–2009



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to country and sector on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/sectors, each country/sector receives fractional credit on basis of proportion of its participating institutions. Sector not available for non-U.S. articles.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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Coauthorship and Collaboration

Article output trends since about the mid-1990s have two defining features: the rapid growth of articles with authors from the developing world, and a rise in the percentage of global article output that is the result of collaboration among researchers internationally. Articles with authors from different institutions in the United States and from different countries have continued to increase, indicating rising knowledge creation, transfer, and sharing among institutions and across national boundaries.[29, 30] This section covers broad trends in coauthorship for the world as a whole and continues with an examination of country-level trends, including selected country-to-country coauthorship patterns and indexes of international collaboration.[31] Indicators of cross-sector coauthorship, which are available only for the United States, are examined below in the section "Trends in Output and Collaboration Among U.S. Sectors."

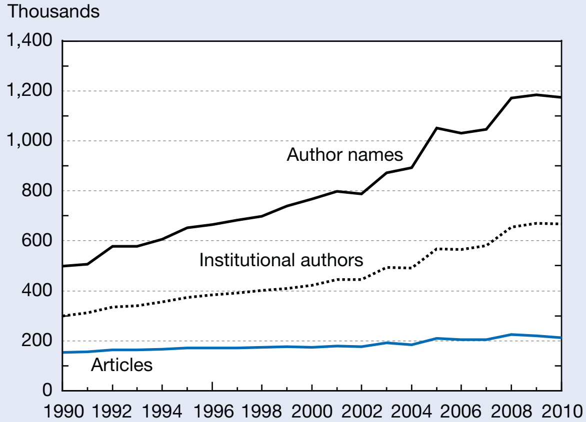
Article Author Names and Institutions

Earlier volumes of this report have noted the imbalance between the growth in number of S&E articles and the growth in the number of authorship credits to institutions and individuals that produced those articles (NSB 2008, 08-01, figure 5-29; NSB 2010, 10-01, table 5-16). The much faster growth in authorship credits to institutions and individuals—in all broad fields—has been used as an indicator of a steady rise in the collaborative nature of S&E research, both domestically and internationally.

Figure 5-23 shows the same trend, but here data are restricted to articles with at least one U.S. *academic* author. Over the period 1990–2010, the number of such articles in the data analyzed in this section increased by an average of 1.6% annually. In contrast, the number of institutions listed on these articles grew over twice as fast at 4.1% annually, and the number of author names grew even faster, at 4.4% annually.

Figure 5-24 focuses on the authors per paper for S&E articles by field with an author from the U.S. academic sector over the same 20-year period. In two decades, the average number of author names per paper in all S&E fields grew from 3.2 to 5.6. The average number of authors per paper more than quadrupled in astronomy (3.1 to 13.8) and doubled in physics (4.5 to 10.1). Growth in the average number of coauthors was slowest in the social sciences (from 1.6 authors per paper in 1990 to 2.1 in 2010) and in mathematics (from 1.7 to 2.2). In short, papers authored by a single U.S. academic scientist or engineering are becoming an increasingly small minority of the published literature. NSF analysis shows that in 2010,

Figure 5-23
U.S. academic S&E articles, institutional authors, and author names: 1990–2010



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database. Articles counted on a whole-count basis. All articles have at least one U.S. academic author and may have authors from other sectors and from outside the U.S. Author name counted each time it appears in data set. Authors assigned to institution on basis of institutional address listed on article; authors from separate departments each counted as individual institutional author; multiple authors from same department of institution considered as one institutional author.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/ products_services/science/.

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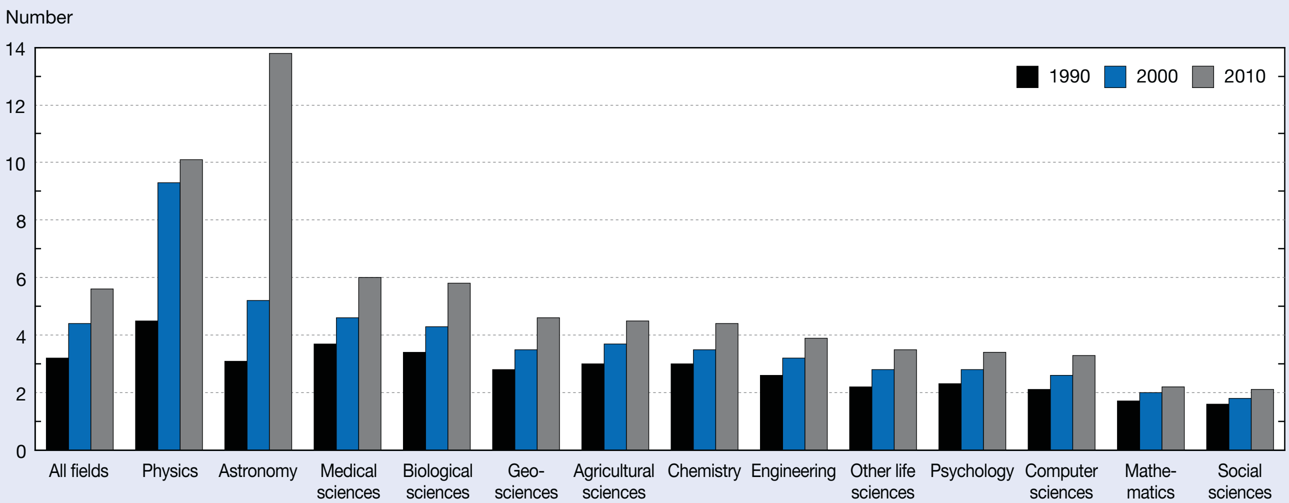
92.4% of all S&E articles with at least one U.S. academic author had two or more author names.

A closely related indicator, coauthored articles (i.e., articles with authors in different institutions or departments or in more than one country) has also increased steadily. Figure 5-25 contrasts these trends for the world as a whole with those for articles with at least one U.S. academic author. Coauthored articles grew from 42% of the world's total S&E articles in 1990 to 67% in 2010. This growth has two parts. Coauthored articles that list only domestic institutions grew from 33% of all articles in 1990 to 43% in 2010. Articles that list institutions from more than one country, that is, internationally coauthored articles (which also may have multiple domestic institutional authors), grew more dramatically—from 10% to 24% over the same period.

The percent of S&E articles with a U.S. *academic* author that is internationally coauthored is higher than the percent of total world international coauthorships (figure 5-25). Purely domestic coauthorship in this sector has been relatively flat in the United States, at about 43% of total U.S. academic articles from 1990 to 2010. Over the same period U.S. academic articles with a non-U.S. coauthor have grown strongly, from 12% to 32%. (These coauthorships may also include multiple domestic U.S. coauthors.) The remainder of this section takes a closer look at patterns within this broad increase in international coauthorship around the world.

Figure 5-24
Number of authors per U.S. academic S&E article, by S&E field: Selected years, 1990–2010



NOTES: Data from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database. All articles have at least one U.S. academic author and may have authors from other sectors and from outside United States.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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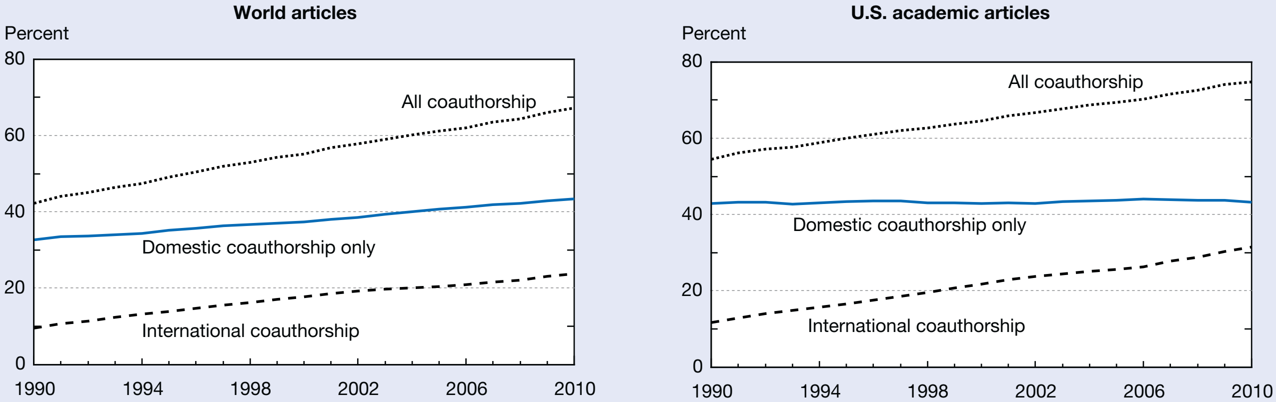
Figure 5-25
World and U.S. academic S&E articles coauthored domestically and internationally: 1990–2010



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating institution or country credited one count. Internationally coauthored articles may also have multiple domestic coauthors.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/ science/.

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International Coauthorship Patterns From a Country Perspective

International coauthorship can be considered from two perspectives: (1) a country's level of participation in the world's total S&E coauthorships, and (2) a country's international coauthorship vis-à-vis the country's total S&E authorship.

World total S&E coauthorship. Table 5-18 shows the world's countries/economies that account for 1% or more of internationally coauthored S&E articles, and how their relative standing, or rank, has changed over the past 10 years. U.S.-based researchers were coauthors of 43% of the world's total internationally coauthored articles in 2010, well above the global percentage of U.S. article output. Germany, the United Kingdom, and France were also leading contributors to the world's internationally coauthored articles. The most notable trend in this indicator, however, was the rise of authors from China, who increased their share of world internationally coauthored S&E articles from 5% to 13% over the last 10 years.

Individual region/country coauthorship. Table 5-19 compares a region/country's share of total world international coauthorship with the region/country's internal or domestic rate of international coauthorship. The table is restricted to countries that had institutional authors on at least 5% or more of the world's internationally coauthored S&E articles in 2010 (see also appendix table 5-41).

The sheer volume of U.S. internationally coauthored articles dominates these measures: 32% of U.S. articles in 2010 were internationally coauthored, up from 23% in 2000. Even higher rates of international coauthorship are evident among the countries of the European Union, where large Framework Research Programs have strongly encouraged it, and in Switzerland. Both Japan's and Asia-8's international coauthorship rates have increased over the past 10 years, and more countries passed the 50% mark over the decade.

Table 5-19 also shows China's idiosyncratic position on this indicator. Table 5-17 shows that China's S&E article output grew sufficiently over the decade to place it as the world's second largest S&E article-producing nation. At the same time, China's internationally coauthored articles as a share of its total article output remained almost flat and, at 27%, was the lowest percentage of all countries/regions shown on Table 5-19. This atypical measure shows that China's very rapid S&E article growth has been driven by articles with solely domestic authors (see discussion below of China's rates of internal and international citations).

What accounts for specific coauthorship relationships? Linguistic and historical factors (Narin et al. 1991), geography, and cultural relations (Glänzel and Schubert 2005) play a role. In recent years, coauthorships in Europe have risen in response to EU policies and incentives that actively encouraged intra-European cross-border collaboration. However, strong ties among science establishments in the Asian region, without the formal framework that characterizes Europe, indicate that regional dynamics can play a strong role in the development of collaborative ties. The discussion below in the section "International Collaboration in S&E" identifies strong coauthorship relationships in specific country pairs across the world, based on the strength of their coauthorship rates.

Table 5-18
Share of internationally coauthored S&E articles worldwide, by region/country: 2000 and 2010
(Percent)

Country/economy	2000	2010
United States	43.8	42.9
Germany	20.0	18.8
United Kingdom	19.0	18.7
France	15.3	13.8
China	5.0	13.0
Canada	9.3	10.1
Italy	9.3	9.4
Japan	10.4	8.2
Spain	6.1	8.1
Australia	5.3	7.1
Netherlands	6.7	6.9
Switzerland	5.8	6.1
Sweden	5.4	4.8
South Korea	2.3	4.4
Belgium	4.0	4.3
Russia	6.9	3.7
India	2.1	3.3
Brazil	2.8	3.0
Austria	2.6	2.9
Denmark	3.1	2.9
Poland	3.2	2.6
Israel	3.0	2.3
Finland	2.6	2.2
Taiwan	1.4	2.2
Norway	1.7	2.1
Portugal	1.2	1.9
Singapore	0.8	1.8
Czech Republic	1.5	1.8
Greece	1.4	1.6
Mexico	1.7	1.6
New Zealand	1.3	1.5
Ireland	0.9	1.4
South Africa	1.0	1.4
Argentina	1.3	1.3
Turkey	0.8	1.2
Hungary	1.7	1.2
Chile	0.8	1.1
Iran	0.2	1.0

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. Countries/economies with less than 1% of world's 2010 international articles omitted.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-41.

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International Coauthorship With the United States

Table 5-20 lists the 31 countries whose institutions appeared on at least 1% of U.S. internationally coauthored articles in 2010. U.S. authors are most likely to coauthor articles with colleagues from the United Kingdom (14.1%), China (13.7%), Germany (13.3%), and Canada (11.8%).

Table 5-19 shows that the rate at which U.S. researchers participate in international collaboration is below that of many countries with smaller science establishments. The large size of the U.S. S&E establishment results in a share

Table 5-19
International collaboration on S&E articles, by selected region/country: 2000 and 2010
(Percent distribution)

	Share of region/country total article output		Share of world's internationally coauthored articles	
Region/country	2000	2010	2000	2010
United States	23	32	44	43
EU				
France	42	56	15	14
Germany	39	54	20	19
Italy	39	48	9	9
Netherlands	45	56	7	7
Spain	36	50	6	8
United Kingdom	35	53	19	19
Other Western Europe				
Switzerland	52	68	6	6
Asia				
China	26	27	5	13
Japan	19	28	10	8
Asia-8	24	30	8	13
Other				
Australia	33	49	5	7
Canada	36	48	9	10

EU = European Union

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. Countries/economies with less than 5% of 2010 international total omitted. See appendix table 5-25 for countries/economies included in Asia-8, which in this table is treated as a single country. Detail adds to more than 100% because articles may have authors from more than two countries/economies.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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Table 5-20
International coauthorship of S&E articles with the United States, by selected country/economy: 2000 and 2010
(Percent)

	2000		2010	
Country/economy	U.S. share of country/economy international articles	Country/economy share of U.S. international articles	U.S. share of country/economy international articles	Country/economy share of U.S. international articles
World	43.8	na	42.9	na
United Kingdom	30.9	13.4	32.3	14.1
China	35.2	4.0	45.2	13.7
Germany	29.7	13.6	30.4	13.3
Canada	52.1	11.0	49.9	11.8
France	25.6	8.9	27.5	8.8
Italy	32.0	6.8	33.4	7.3
Japan	42.3	10.0	36.9	7.0
South Korea	59.8	3.2	53.8	5.5
Australia	35.4	4.3	32.0	5.3
Spain	27.0	3.8	27.9	5.3
Netherlands	29.7	4.5	31.1	5.0
Switzerland	31.2	4.1	31.1	4.4
Sweden	27.6	3.4	29.2	3.3
Israel	51.8	3.5	53.9	2.8
Brazil	38.9	2.5	39.7	2.8
Taiwan	61.2	1.9	51.2	2.6
India	38.1	1.8	33.5	2.5
Belgium	23.3	2.1	24.7	2.5
Russia	24.8	3.9	27.1	2.3
Denmark	29.6	2.1	30.8	2.0
Austria	26.7	1.6	25.9	1.8
Poland	26.3	1.9	27.4	1.7
Mexico	42.3	1.6	44.4	1.6
Finland	30.8	1.8	28.8	1.5
Norway	28.0	1.1	28.9	1.4
Greece	27.2	0.9	35.0	1.3
Singapore	27.0	0.5	31.0	1.3
New Zealand	33.1	1.0	34.4	1.2
South Africa	33.2	0.8	36.5	1.2
Turkey	39.7	0.7	40.6	1.1
Argentina	34.6	1.0	35.0	1.1

na = not applicable

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. Countries/economies ranked on percentage of their share of U.S.'s international articles in 2010; countries/economies with less than 1% of U.S.'s 2010 international articles omitted.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-41.

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of U.S. internationally coauthored articles that is lower than those of most other countries. Scientists and engineers in countries with smaller S&E establishments, in order to find an appropriate coauthor, must more frequently turn to coauthors abroad, resulting in relatively larger shares of those countries' S&E articles that are coauthored with U.S. scientists and engineers. These relationships are summarized in table 5-20.

For example, 2.8% of U.S. internationally coauthored articles in 2010 had an Israeli coauthor. The corresponding figure for Israel, with its much smaller scientific infrastructure, is 53.9%. Also, 49.9% of Canada's internationally coauthored articles had a U.S. coauthor, but only 11.8% of U.S. international coauthorship was with a colleague at a Canadian institution.[32] Linguistic, geographic, and other ties underlie these collaborations.

Notable changes in these patterns of U.S. international coauthorship parallel changes in other indicators discussed in this section. As China's total S&E article output grew rapidly, so did its coauthorship with U.S. authors: the U.S. share of China's internationally coauthored articles increased about 10 percentage points to 45.2% over the past decade, and China's share of U.S. internationally coauthored articles increased 9.7 percentage points to 13.7% (table 5-20). In contrast, U.S. scientists and engineers lost relative share of international coauthorship elsewhere (e.g. Japan, Australia, Taiwan, and South Korea) as their counterparts broadened the geographic scope of their collaborations with foreign scientists and engineers.

An Index of International Collaboration in S&E

The size of countries' S&E systems conditions the scope and reach of their international collaborations (Glänzel and Schubert 2004). An index of international collaboration addresses this issue. This index is a ratio of country A's percentage of country B's international coauthorships to country A's percentage of total international coauthorship (Narin et al. 1991) (see sidebar, "Calculating the Index of International Collaboration"). An index value substantially greater than 1 indicates strong collaborative ties, and a value substantially below 1 signals relatively infrequent collaboration. The 1995 and 2010 indexes for country pairs that produced more than 1% of all internationally coauthored articles in 2010 are shown in appendix table 5-42.

Table 5-21 lists the international collaboration index for selected pairs of countries. In North America, the Canada-United States index shows a rate of collaboration that is slightly greater than would be expected based solely on the number of internationally coauthored articles produced by these two countries, and the index has changed little over the past 15 years. The United States-Mexico index is just about as would be expected and is also stable.

Mexico-Argentina scientific collaboration networks are strong at 3.5, well above expected levels. In South America, the collaboration index of Argentina-Brazil, at 5.1, is one of the highest in the world.

Collaboration indexes between pairs of countries on opposite sides of the North Atlantic are all low and have changed little over the past 15 years. In Europe, collaboration patterns are mixed but most have increased, indicating growing integration across the European Union for S&E article publishing. Among the large publishing countries (Germany, the United Kingdom, and France) collaboration was less than expected, but grew in all three countries over 15 years. A particularly strong collaboration network has developed between scientists in Poland and the Czech Republic.

The Scandinavian countries[33] increased their collaboration indexes with many countries elsewhere in Europe (appendix table 5-42). Within Scandinavia, the indexes are among the highest in the world (table 5-21).

Cross-Pacific collaboration patterns are mixed. Japan-United States collaboration fell below the expected value over the 15 years, while the United States-China index rose to 1. U.S. collaboration with South Korea and Taiwan weakened but remained higher than expected in both cases. The international collaboration indexes between Canada and countries in Asia are lower than the U.S.-Asia indexes.

Collaboration indexes within Asia and across the South Pacific between the large article producers are generally higher than expected, but have experienced some weakening. Australia's coauthorships are strongly linked to New Zealand. Two strongly collaborating pairs are South Korea-Japan and Australia-Singapore, but each of these networks has declined in strength. India's collaborations with both South Korea and Japan grew stronger between 1995 and 2010.

Calculating the Index of International Collaboration

Appendix table 5-41 contains the raw data for calculating the 2010 indexes of international collaboration contained in appendix table 5-42. Using the data for the world, China, and the United States, the 2010 U.S.-China index is computed as follows:

- China-U.S coauthorships as a proportion of U.S. international coauthorship = 10,917 / 79,581 = 0.1372
- China's percentage of total international coauthorship = 24,164 / 185,303 = 0.1304
- U.S.-China coauthorships as a percentage of China's international coauthorship = 10,917 / 24,164 = 0.4518
- U.S. percentage of total international coauthorship = 79,581 / 185,303 = 0.4295

The indexes for any country pair are always symmetrical. The China-U.S. and U.S.-China index are the same, as follows:

- China-U.S. index: 0.1372 / 0.1304 = 1.05 and
- U.S.-China index: 0.4518 / 0.4295 = 1.05

The 2010 China-U.S. index value is essentially 1, the "expected" index value when two countries coauthor with each other at the same rate as they coauthor with all countries. This is an increase since 1995, when the index was 0.83.

Trends in Output and Collaboration Among U.S. Sectors

In the U.S. innovation system, ties between and among universities, industry, and government can be beneficial for all sides. These ties include the flows of knowledge among these sectors, for which research article outputs and collaboratively produced articles are proxy indicators. S&E articles authored at academic institutions have for decades

Table 5-21
Index of international collaboration on S&E articles, by selected country/economy pair: 1995 and 2010

	International collaboration index	
Country/economy pair	1995	2010
North/South America		
Canada–United States	1.16	1.16
Mexico–United States	0.97	1.03
United States–Brazil	0.89	0.92
Argentina–Brazil	3.93	5.12
Mexico–Argentina	2.48	3.46
North Atlantic		
UK–United States	0.68	0.75
Germany–United States	0.66	0.71
France–United States	0.59	0.64
Canada–France	0.60	0.78
Europe		
France–Germany	0.74	0.98
France–UK	0.71	0.93
Germany–UK	0.64	0.93
Belgium–Netherlands	2.41	2.85
Italy–Switzerland	1.48	1.53
Poland–Czech Republic	1.96	3.93
Hungary–Germany	1.22	1.42
Germany–Czech Republic	1.23	1.40
Scandinavia		
Finland–Sweden	3.45	3.97
Norway–Sweden	4.30	4.16
Sweden–Denmark	3.29	3.54
Finland–Denmark	2.73	3.02
Pacific Rim		
Japan–United States	1.04	0.86
China–United States	0.83	1.05
South Korea–United States	1.39	1.25
Taiwan–United States	1.59	1.19
China–Canada	0.75	0.74
Japan–Canada	0.64	0.56
Asia/South Pacific		
China–Japan	1.49	1.26
South Korea–Japan	2.49	1.94
Australia–Singapore	2.01	1.66
Australia–China	1.11	1.06
Australia–New Zealand	4.49	3.92
India–Japan	0.72	1.13
India–South Korea	1.25	2.12

UK = United Kingdom

NOTES: International collaboration index shows first country's rate of collaboration with second country divided by second country's rate of international coauthorship. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-42.

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accounted for more than 70% of all U.S. articles, and this percentage has been slowly rising—to 76% in 2010 (table 5-22), primarily as a result of declines in articles with authors from industry (for a discussion of this shift, see NSB 2008). This section contrasts U.S. academic authorship with nonacademic authorship, including output trends by sector and trends in coauthorship, both between U.S. sectors and between U.S. sectors and authors abroad.

Article Output by Sector

Total annual S&E articles by authors in U.S. nonacademic sectors changed little over the past decade, ranging from 48,000 to 55,000 articles[34] per year between 1995 and 2010 (appendix table 5-43). The number of articles produced by scientists and engineers in the federal government and in industry was more than 15,000 in each sector in 1995 but slowly declined through 2010, and each sector lost share over that period (table 5-22). State and local government authorship, dominated by articles in the medical and biological sciences, has remained constant. Scientists and engineers in the private nonprofit sector increased their output to about 18,000 in 2008 and then declined to near 17,000 in 2010 (appendix table 5-43).

Federally funded research and development centers (FFRDCs) are research institutions that are sponsored by federal agencies and administered by universities, industry, or other nonprofit institutions. FFRDCs have specialized research agendas closely related to the mission of the sponsoring agency and may house large and unique research instruments not otherwise available in other research venues.

Table 5-22
U.S. S&E articles, by sector: Selected years, 1995–2010
(Percent)

Sector	1995	2000	2005	2010
Federal government	7.9	7.2	6.6	6.1
Industry	8.1	7.3	6.4	5.8
Academic	71.6	72.8	74.6	76.1
FFRDCs	2.8	2.7	2.8	2.4
Private nonprofit	8.0	8.5	8.2	8.6
State/local government	1.0	0.9	0.9	0.9

FFRDCs = federally funded research and development centers

NOTES: Detail does not add to 100% because joint and unknown sectors omitted. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on basis of proportion of its participating institutions.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-43.

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Although authors at FFRDCs published articles in all of the broad S&E fields considered in this chapter, articles in physics, chemistry, and engineering together represented 71% of publication by this sector in 2010, reflecting the more specialized research programs in FFRDCs (appendix table 5-43).[35]

In contrast, articles published by authors in the private nonprofit sector are primarily in the medical sciences (54% of the sector's articles in 2010) and biological sciences (25%) (appendix table 5-43). Federal government authors show a similar pattern, with 30% in the biological sciences and 28% in the medical sciences.

Trends in Sector Coauthorship

Coauthorship data are indicators of collaboration at the sectoral level between U.S. institutional authors and between U.S. sectors and foreign institutions.[36] These data show that the growing integration of R&D activities, as measured by coauthorship, is occurring across R&D-performing U.S. institutions in all sectors.

Overall, the largest increases in this integration have been driven by increased coauthorship between U.S. academic authors and non-U.S. authors (in all sectors; NSF data do not identify the sectors of non-U.S. authors) (table 5-23). Co-authorship between non-U.S. authors and U.S. academic authors increased over the decade by 9.9 percentage points.

Between 2000 and 2010, coauthorship within sectors increased for all U.S. sectors.[37] Coauthorship within academia rose from 39% in 2000 to 47% in 2010. FFRDC to FFRDC coauthorship increased 6 percentage points (table 5-23). Because most publishing scientists and engineers are in the academic sector, non-academic scientists and engineers turn to academia for collaborators, so the resulting rates of cross-sector coauthorship with academic authors are quite high and continue to increase. Because of the predominance of the academic sector in S&E article publishing in the United States, academic scientists and engineers have been on the forefront of integrating S&E research across institutions, both nationally and internationally.

Table 5-23
U.S. S&E article coauthorship, by sector, foreign coauthorship, and U.S. coauthor sector: 2000 and 2010
(Percent)

		U.S. coauthor sector					
Sector	Foreign coauthor	Federal government	Industry	Academic	FFRDCs	Private nonprofit	State/local government
2000							
Federal government	21.2	18.1	9.2	55.0	3.1	9.6	2.5
Industry	22.5	9.6	14.5	45.6	3.1	10.3	1.5
Academic	21.7	7.8	6.2	38.6	2.8	9.2	1.5
FFRDCs	35.0	8.0	7.6	51.2	13.4	4.2	0.2
Private nonprofit	20.4	8.4	8.6	57.0	1.4	25.1	2.4
State/local government	11.7	16.2	9.4	68.2	0.6	18.2	13.8
2010							
Federal government	29.6	21.8	10.6	64.8	4.6	14.9	3.1
Industry	31.5	11.8	19.3	55.4	3.8	16.0	2.1
Academic	31.6	8.3	6.4	46.9	3.4	11.7	1.6
FFRDCs	46.4	10.9	8.0	62.2	19.4	8.0	0.3
Private nonprofit	31.6	10.8	10.5	66.5	2.5	30.3	2.8
State/local government	18.8	18.8	11.5	75.6	0.7	23.1	15.6
2000–10 change (percentage points)							
Federal government	8.4	3.7	1.4	9.8	1.5	5.2	0.6
Industry	9.1	2.2	4.8	9.8	0.7	5.7	0.6
Academic	9.9	0.5	0.2	8.3	0.6	2.4	0.1
FFRDCs	11.3	2.9	0.4	11.0	6.0	3.7	*
Private nonprofit	11.2	2.5	1.9	9.5	1.0	5.2	0.3
State/local government	7.1	2.6	2.1	7.4	0.1	4.9	1.8

* = rounds to zero

FFRDCs = federally funded research and development centers

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered the database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country or sector credited one count. Articles from joint or unknown sectors omitted. Articles may have authors from more than two sectors. Articles with authors from a single sector omitted from table.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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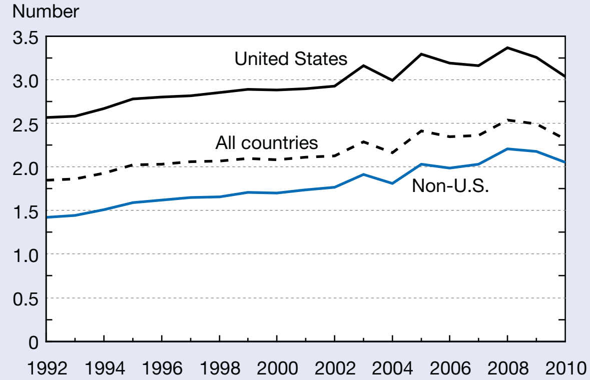
As discussed earlier in this chapter, international collaboration has increased rapidly in the United States. International coauthorship across the U.S. sectors rose by 7–11 percentage points between 2000 and 2010 (table 5-23). Articles from FFRDCs reached the highest rate of collaboration with foreign authors, at 46%, followed by those from academia, private nonprofit institutions, industry, and the federal government, at roughly 30% each.

Trends in Citation of S&E Articles[38]

Citations indicate influence, and they are increasingly international in scope. When scientists and engineers cite the published papers resulting from prior S&E research, they are formally crediting the influence of that research on their own work.[39] Citations are generally increasing in volume relative to S&E articles. In 1992, an S&E article received, on average, 1.85 citations. In contrast, an S&E article in 2010 received on average 2.32 citations (Figure 5-26). Articles with U.S. authors tended to receive more citations than others, but the gap narrowed over the period as the total share of U.S.-authored articles declined.[40]

Like the indicators of international coauthorship discussed above, cross-national citations are evidence that S&E research is increasingly international in scope. Two other trends accompanied the steady growth of international citations in the world's S&E literature: changing shares of total citations across countries and changing shares of highly cited S&E literature. These are discussed in the following sections.

Figure 5-26
Average citations per S&E article, by country of author: 1992–2010



NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2008 are references made in articles in 2008 data tape to articles in 2004–06 data tapes.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/ science/.

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Citation Trends in a Global Context

Shares of the world total of citations to S&E research articles have changed concurrently with shares of the world total of these articles. Table 5-24 shows, for example, that between the periods 1996–98 and 2006–08, the U.S. share of world S&E articles declined from 32% to 28% across all fields.[41] The U.S. share declined in every broad field, although the decline varied in size. Table 5-24 shows parallel trends for the U.S. share of citations and indicates an even larger decline, from 45% to 36%.

China's share of total world S&E articles and citations increased over the same period. However, in contrast to the global trend of increasing international citations, China's pattern has been different. Unlike the United States and other large article-producing countries/regions, the share of China's citations that are international citations *decreased* between 2000 and 2010, from 60% to 51% (figure 5-27), suggesting that much of the use of China's expanding S&E article output—as indicated by citations to those articles—is occurring *within* China.[42]

Trends in Highly Cited S&E Literature

Another indicator of performance of a national or regional S&E system is the share of its articles that are highly cited. High citation rates can indicate that an article has a greater impact on subsequent research than articles with lower citation rates.

Appendix table 5-44 shows citation percentiles for 2000 and 2010 by field for the top five S&E article-producing countries/regions.[43] In that table, a country whose global research influence was high would have higher proportions of articles in higher citation percentiles, whereas a country whose influence was low would have greater proportions of articles in lower citation percentiles. In other words, a country whose research is highly influential would have higher shares of its articles in higher citation percentiles.

World citations to U.S. research articles show that U.S. articles continue to have the highest citation rates across all broad fields of S&E. In both 2000 and 2010, as displayed in appendix table 5-44, the U.S. share of articles in the 99th percentile was higher than its share in the 95th percentile, and these were higher than its share in the 90th percentile, and so forth, even while U.S. shares of all articles and all citations were decreasing. In 2010, U.S. articles represented 28% of the world's total of 2.3 million articles in the cited period shown; the U.S. authored 49% of the rare 21,900 articles in the 99th percentile and 24% of the 1.3 million articles in the 50th percentile.

Only U.S. publications display the preferred relationship of strongly higher proportions of articles in the higher percentiles of article citations. When cited, articles with authors

Table 5-24
S&E articles, citations, and international citations, by selected region/country: 2000 and 2010
(Percent)

Region/country	Share of world articles (cited years) 1996–98	2006–08	Share of world citations (citing year) 2000	2010	Share of region/country citations that are international (citing year) 2000	2010
United States	32.4	27.8	44.8	36.4	48.1	53.7
EU	35.4	32.4	33.3	32.8	44.8	49.7
China	2.0	7.5	0.9	6.0	60.3	50.8
Japan	8.8	7.0	7.1	5.7	62.3	70.2
Asia-8	4.1	7.4	1.8	5.3	62.9	65.0

EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-25 for countries/economies included in EU and Asia-8, which in this table are treated as single countries. Citation counts based on 3-year period with 2-year lag (e.g., citations for 2000 are references made in articles in 2000 data tape to articles in 1996–98 data tapes); data shown are for the 3 years in cited year window.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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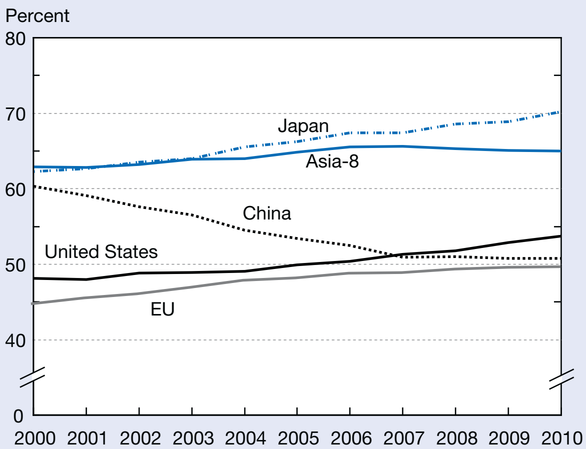
Figure 5-27
Share of selected country/region citations that are international: 2000–10



EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/region on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/regions, each country/region receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-25 for countries included in EU and Asia-8, which in this table are treated as single countries. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2009 are references made in articles in 2009 data tape to articles in 2005–07 data tapes.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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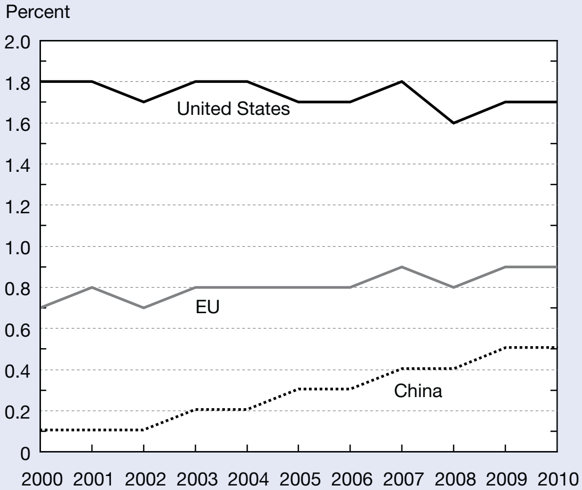
from the European Union, China, Japan, and the Asia-8 are more often found in the lower citation percentiles. (These data are summarized in appendix table 5-45.) Nevertheless, as the U.S. share of all articles produced declined between 2000 and 2010, its share of articles in the 99th percentile (i.e., the top 1%) of cited articles also declined, particularly in some fields. Shares in the top percentile increased for the European Union, China, Japan, and the Asia-8.

To control for changing shares of the world's S&E articles, Figure 5-28 shows the percentage of total articles for each of the United States, European Union, and China that appears in the world's top 1% of cited articles. Across the decade, 1.6%–1.8% of U.S.-authored S&E articles have appeared in the world's top 1% of cited articles, compared with 0.7%–0.9% of articles from the EU. China's articles in the top 1% of cited articles remained behind the United States and European Union but increased from 0.1% to 0.5% over the period.

When citation rates are normalized by the share of world articles during the citation period to produce an index of highly cited articles, the influence of U.S. articles has changed little over the past 10 years. Between 2000 and 2010, the U.S. index of highly cited articles barely changed (from 1.85 to 1.76) (figure 5-29 and appendix table 5-45) and remained well above the expected index value of 1. During the same period, the EU increased its index from 0.73 to 0.93, and China, Japan, and the Asia-8 increased their index values but remained below their expected values. In other words, the United States had 76% more articles than expected in the 99th percentile of cited articles in 2010, and the EU had 7% fewer than expected. China had 51% fewer articles in the 99th percentile than expected in 2010, and Japan 39% fewer.

Figure 5-28
Share of U.S., EU, and China S&E articles that are in the world's top 1% of cited articles: 2000–10



EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/regions, each country/region receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-25 for countries included in EU, which in this figure is treated as a single country. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2009 are references made in articles in 2009 data tape to articles in 2005–07 data tapes.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/.

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The United States experienced gains on the index of highly cited articles in engineering, astronomy, other life sciences, and psychology and declines in chemistry, geosciences, and mathematics, although all remained well above expectation (appendix table 5-45). The EU reached its expected value in engineering, chemistry, physics, and the agricultural sciences. Japan and the Asia-8 countries did not achieve the expected value of 1 in any broad field.

Notably, China achieved an index value of near 1 in engineering and computer sciences (figure 5-30). In most broad fields, China's indexes of highly cited articles were higher in 2010 than in 2000. In a few fields—the biological, medical, and social sciences—the Chinese index remained low, and these fields kept the index for all fields below 0.5 in 2010 (appendix table 5-45).

Academic Patents, Licenses, Royalties, and Startups

Other indicators of academic R&D outputs reflect universities' efforts to develop their intellectual property for possible commercial use in the form of patents and associated activities. The majority of U.S. universities did not become actively involved in managing their own intellectual property until late in the 20th century, although some were granted patents much earlier.[44] The Bayh-Dole Act of 1980 gave colleges and universities a common legal framework for claiming ownership of income streams from patented discoveries that resulted from their federally funded research. To facilitate the conversion of new knowledge produced in their laboratories to patent-protected public knowledge that can be potentially licensed by others or form the basis for a startup firm, more and more research institutions established technology management/transfer offices (Association of University Technology Managers 2009).

The following sections discuss overall trends in university patenting and related indicators through 2009–10.

University Patenting Trends

U.S. Patent and Trademark Office (USPTO) data show that annual patent grants to universities and colleges ranged from 2,900 to 4,500 between 1998 and 2010 (appendix table 5-46).[45]

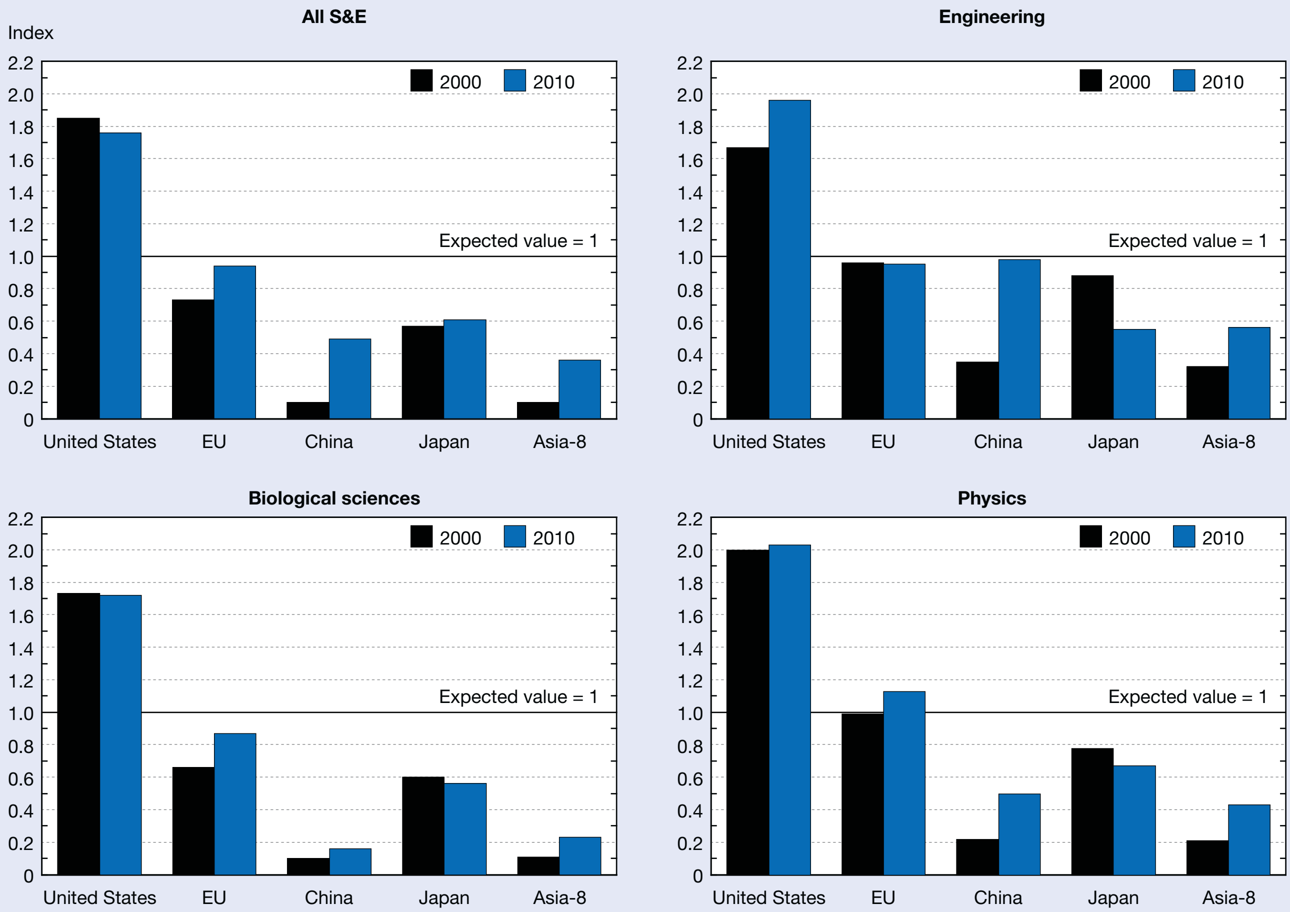
The top 200 R&D-performing institutions, with 97% of the total patents granted to U.S. universities during the 1998–2010 period, dominate among universities and university systems receiving patent protection.[46] College and university patents have been about 4.2–4.7% of U.S. nongovernmental patents for a decade. Among the top R&D-performing institutions that received patents between 1998 and 2010, 19 accounted for more than 50% of all patents granted to these institutions (although these included a few multicampus systems, including the Universities of California and Texas). The University of California system received 11.9% of all U.S. patents granted to U.S. universities over the period, followed by the Massachusetts Institute of Technology with 4.2% of all U.S. patents granted to U.S. universities.

Biotechnology patents account for the largest percent (30%) of U.S. university patents in 2010 (appendix table 5-47), and have grown over the past 15 years (figure 5-31). Pharmaceutical patents, the next largest technology area, have more recently begun to decline, from nearly 450 a year in the late 1990s to about 300 in more recent years. Patents for measuring devices, semiconductors, and optics have all increased gradually over the past two decades.

Patent-Related Activities and Income

Data from the Association of University Technology Managers (AUTM) indicate continuing growth in a number of patent-related activities. Invention disclosures filed with university technology management offices describe prospective inventions and are submitted before a patent application is filed. These grew from 12,600 in 2002, to 18,200 in

Figure 5-29
Index of highly cited articles, by selected S&E field and region/country: 2000 and 2010



EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles/citations classified by year they entered database, rather than year of publication, and assigned to country/region on basis of institutional address(es) listed on article. See appendix table 5-25 for countries included in EU and Asia-8. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2010 are references made in articles in 2010 data tape to articles in 2006–08 data tapes. Index of highly cited articles is country's share of world's top 1% cited articles divided by its share of world articles for the cited year window.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-45.

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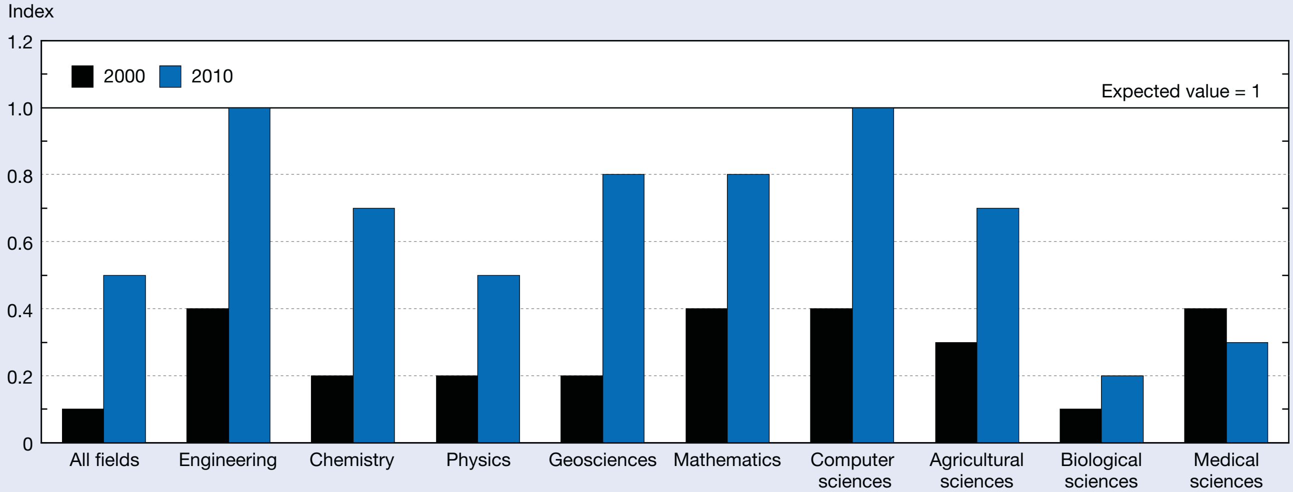
2009 (notwithstanding small shifts in the number of institutions responding to the AUTM survey over the same period) (figure 5-32). Likewise, new U.S. patent applications filed by AUTM university respondents also increased, from 6,500 in 2001, to 11,300 in 2009. U.S. patents awarded to AUTM respondents stayed flat over the period, at about 3,000 per year with some fluctuation.[47]

The AUTM survey respondents reported 348 startup companies formed in 2003 and 555 in 2009, with a total of extant startup companies in 2009 of 3,175 (appendix table 5-48). Licenses and options that generated revenues also increased over the period. However, active licenses, while increasing steadily from 1999 to 2008, declined slightly in 2009; this decline may reflect the downturn in the U.S. economy in that period.

Most royalties from licensing agreements accrue for relatively few patents and the universities that own them, and many of the AUTM respondent offices report no income. (Thursby and colleagues [2001] report that the objectives of university technology management offices include more than royalty income.) At the same time, large one-time payments to a university can affect the overall trend in university licensing income. In 2009, the 153 institutions that responded to the AUTM survey reported a total of $1.5 billion in net royalties from their patent holdings, down sharply from the previous 2 years, perhaps as a result of the nation's economic downturn in 2008–09 (appendix table 5-48).

Figure 5-30
Chinese index of highly cited articles, by selected S&E field: 2000 and 2010



NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles/citations classified by year they entered database, rather than year of publication, and assigned to country on basis of institutional address(es) listed on article. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2010 are references made in articles in 2010 data tape to articles in 2006–08 data tapes. Index of highly cited articles is country's share of world's top 1% cited articles divided by its share of world articles for the cited year window.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/. See appendix table 5-45.

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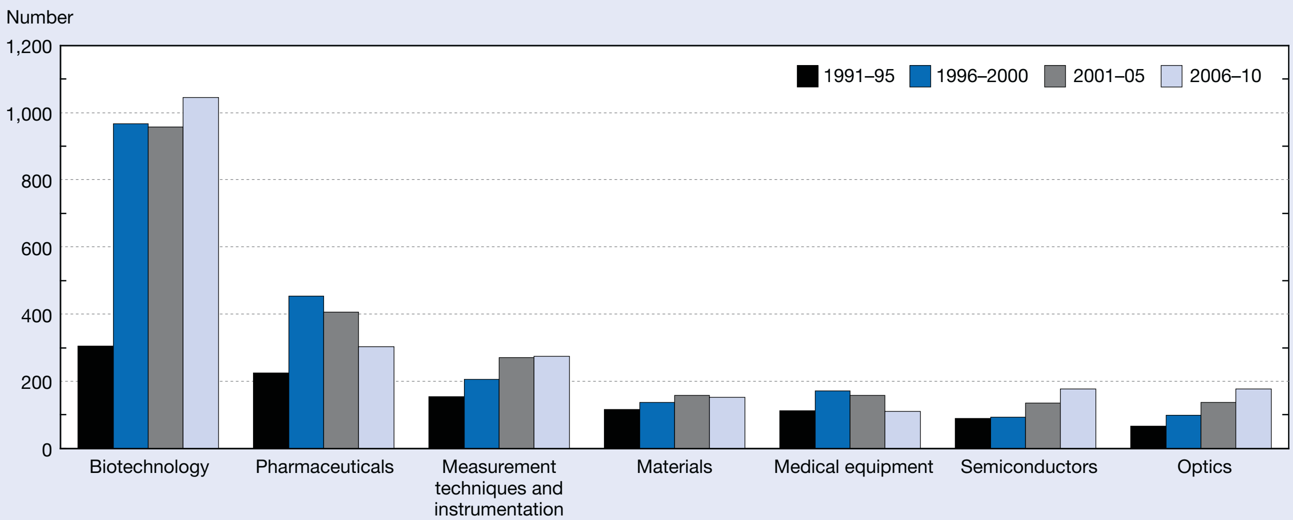
Figure 5-31
U.S. academic patents, by technology area: Selected 5-year averages, 1991–2010



NOTES: Data include institutions affiliated with academic institutions, such as university and alumni organizations, foundations, and university associations. Universities vary in how patents assigned, e.g., to boards of regents, individual campuses, or entities with or without affiliation with university. The Patent Board™ technology areas constitute an application-oriented classification system that maps the thousands of International Patent Classes (IPCs) at main group level into 1 of 35 technology areas. If patent has more than one IPC, only primary IPC is considered in mapping. Data in figure not comparable to previous versions of the figure due to changes in classification system.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from U.S. Patent and Trademark Office (USPTO), Patent Grant Bibliographic Data.

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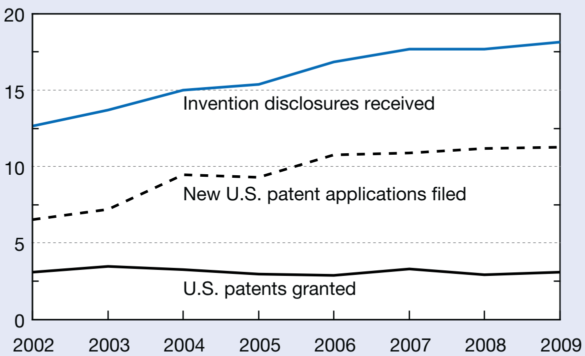
Figure 5-32
U.S. university patenting activities: 2002–2009



SOURCE: Association of University Technology Managers (AUTM), AUTM Licensing Surveys: 2002–2009. See appendix table 5-48.

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Patent-to-Literature Citations

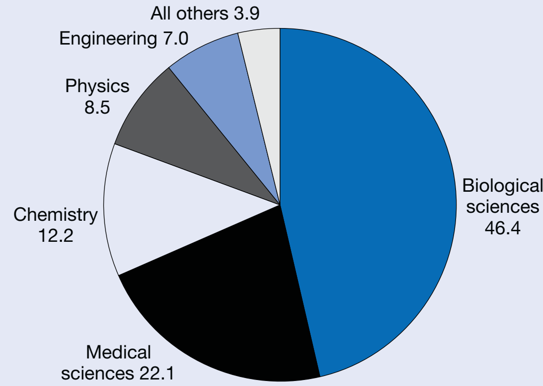
Citations to the S&E literature on the cover pages of issued patents are one indicator of the contribution of research to the development of practical innovations.[48] This indicator of how science links to invention increased sharply in the late 1980's and early 1990's (Narin, Hamilton, and Olivastro 1997), due in part to developments in U.S. policy, industry growth and maturation, and court interpretation. At the same time, patenting activity by academic institutions was increasing rapidly, as were patent citations to S&E literature produced across all sectors (NSB 2008, pp. 5-49 to 5-54).

Between 1998 and 2010, growth for this indicator was much slower. Of utility patents awarded to both U.S. and foreign assignees, 11% cited the S&E articles analyzed in this chapter in 2010 (appendix table 5-49). Concomitant with a growth in the percentage of U.S. utility patents awarded to foreign assignees, nearly 50% of the citations to the S&E literature in 2010 cited non-U.S. S&E articles.

In 2010, five broad S&E fields (biological sciences, medical sciences, chemistry, physics, and engineering) accounted for 96% of the citations to U.S. articles in USPTO patents (figure 5-33 and appendix table 5-50). These citations are dominated by articles in the biological sciences, at 46% of the total (compare with patents awarded by technology area, figure 5-31).

Considering only citations to U.S. articles, growth in citations has been uneven across the sectors and thus sector shares have changed somewhat (appendix table 5-49). Citations to articles authored in the industry, nonprofit, and government sectors have lost share, largely to articles from academia, which grew from 58% to 64% of the total citations to U.S. articles between 1998 and 2010. Appendix table 5-50 summarizes the increasing role of citations to U.S. academic articles in the science linkage to U.S. patents. Of the five broad fields of S&E that accounted for virtually all patent citations to U.S. academic articles, increased shares

Figure 5-33
Citations of U.S. S&E articles in U.S. patents, by selected S&E article field: 2010



NOTES: Citations are references to S&E articles in journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Citation counts based on a 6-year window with 5-year lag, e.g., citations for 2010 are references in U.S. patents issued in 2010 to articles published in 2000–05.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from U.S. Patent and Trademark Office (USPTO), Patent Grant Bibliographic Data, and Thomson Reuters, SCI and SSCI, http://www.thomsonreuters.com/products_services/ science/. See appendix table 5-50.

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of academic citations were notable in engineering (from 46% to 63%) and physics (from 43% to 66%).

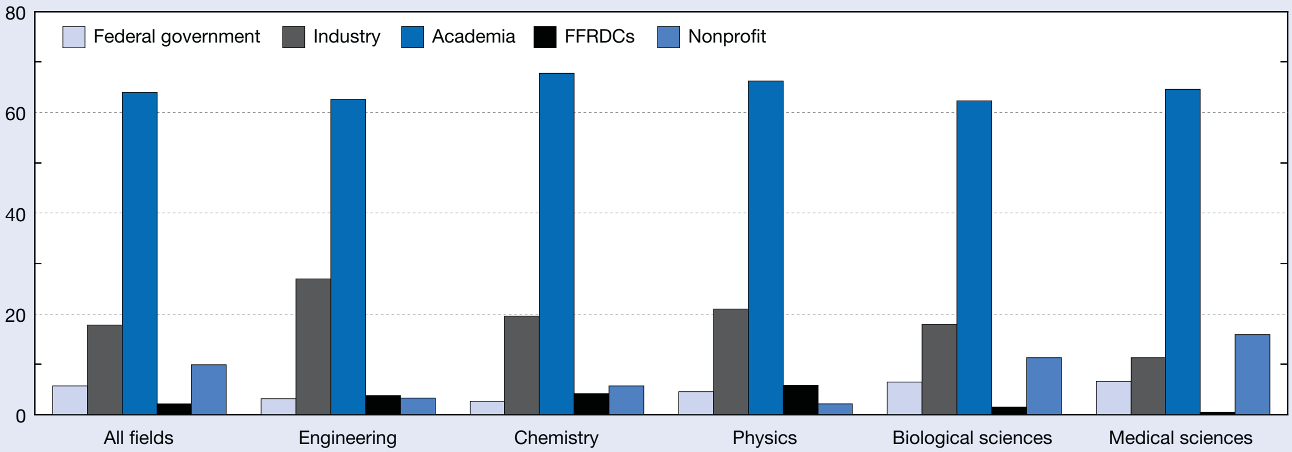
Figure 5-34 shows, within the most cited S&E fields, the distribution by U.S. sector of citations to articles in U.S. patents in 2010. As noted above, academic articles dominate across all of the fields shown, from 62% in the biological sciences to 68% in chemistry. U.S. government-authored articles received 7% of the 2010 patent citations in both the biological and medical sciences. S&E articles from industry accounted for 27% of the engineering citations and about one-fifth of the articles cited in chemistry and physics. FFRDC-authored articles accounted for 6% of the physics citations.

Energy and Environment-Related Patent Citations

NSF developed a set of four filters for identifying patents with potential application in pollution mitigation and in alternative means of energy production, storage, and management. (See sidebar "Identifying Clean Energy and Pollution Control Patents" for details on the filters.) These include patents slated by the federal government for fast-track review at USPTO.[49]

Chapter 6 of this volume presents extensive data on the patents in these four technology areas, including the nationality of their assignees. (See chapter 6, "Patenting of clean energy and pollution control technologies.") This section reports on the citations in those patents to the S&E literature, using those citations to indicate the linkages between S&E

Figure 5-34
Citations of U.S. S&E articles in U.S. patents, by selected S&E field and article author sector: 2010



FFRDC = federally funded research and development center

NOTES: Citations are references to U.S. S&E articles in journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Citations on fractional-count basis, i.e., for cited articles with collaborating institutions from more than one sector, each sector receives fractional credit on basis of proportion of its participating institutions. Citation counts based on a 6-year window with 5-year lag, e.g., citations for 2010 are references in U.S. patents issued in 2010 to articles published in 2000–05. Detail may not add to total because of rounding.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from U.S. Patent and Trademark Office (USPTO), Patent Grant Bibliographic Data, and Thomson Reuters, SCI and SSCI, http://www.thomsonreuters.com/products_services/science/.

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Identifying Clean Energy and Pollution Control Patents

Using a combination of U.S. Patent Classification and International Patent Classification codes and text strings, NSF developed algorithms to identify USPTO-issued patents with potential application in four broad "green" technology areas. The four technology areas and their main sub-categories are listed below. The search codes used to locate relevant patents will be available in D'Amato et al. (2012 forthcoming), which documents the process used in developing these patent filters.

Alternative energy production	Energy storage	Energy management (smart grid)	Pollution mitigation
Bioenergy	Batteries	Advanced components	Recycling
Geothermal	Flywheels	Sensing and measurement	Air
Hydropower	Superconducting magnetic energy systems	Advanced control methods	Solid waste
Nuclear	Ultracapacitors	Improved interfaces and decision support	Water
Solar	Hydrogen production and storage	Integrated communication	Environmental remediation
Wave/tidal/ocean	Thermal energy storage		Cleaner coal
Wind	Compressed air		Carbon and greenhouse gas capture and storage
Electric/hybrid vehicles			
Fuel cells			

R&D[50] and the potential for practical use of the results of those R&D projects in new inventions and technologies.

Five broad S&E fields dominate the citations to S&E literature in these four patent areas: chemistry, physics, engineering, the biological sciences, and geosciences (which in this taxonomy includes the environmental sciences). The range of S&E fields cited indicates that these developing technologies rely on a wide base of S&E knowledge.[51]

The S&E fields cited by these patents are shown in table 5-25. Thirty-five percent of the citations in alternative energy patents that cite S&E articles were to chemistry articles, followed by articles from physics (28%), engineering (20%), and the biological sciences (15%).

Chemistry also dominates the citations in patents for energy storage systems, at 54%., followed by citations to articles in engineering (20%), physics (16%), and the biological sciences (9%).

Patents with potential for application in pollution mitigation processes cite S&E articles most often in chemistry, at 31%. The biological sciences, geosciences, and engineering each receive about one-fifth of the citations in these patents.

Smart grid is a set of patents related to efficient use and distribution of energy. Two fields dominate the S&E article citations in these patents: physics (52%) and engineering (40%).

Table 5-25
Patent citations to S&E articles, by selected patent technology area and article field: 1998–2010

Technology/field	Citations (*n*)	Percent
Alternative energy	7,852	100.0
Chemistry	2,770	35.3
Physics	2,171	27.6
Engineering	1,532	19.5
Biological sciences	1,179	15.0
Geosciences	116	1.5
All others	84	1.1
Energy storage	3,909	100.0
Chemistry	2,106	53.9
Engineering	783	20.0
Physics	637	16.3
Biological sciences	338	8.6
All others	45	1.2
Smart grid	1,433	100.0
Physics	750	52.3
Engineering	572	39.9
Computer sciences	33	2.3
Biological sciences	31	2.2
Geosciences	20	1.4
Chemistry	19	1.3
All others	8	0.6
Pollution mitigation	5,390	100.0
Chemistry	1,643	30.5
Biological sciences	1,162	21.6
Geosciences	1,088	20.2
Engineering	1,068	19.8
Physics	211	3.9
Agricultural sciences	136	2.5
All others	82	1.5

NOTES: Citations are references to S&E articles in journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Citation counts based on a 6-year window with 5-year lag, e.g., citations for 2002 are references in U.S. patents issued in 2002 to articles published in 1992–97. Patents may appear in more than one technology area and thus citation counts may overlap slightly. See sidebar "Identifying clean energy and pollution control patents" for details on these technology areas.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, and The Patent Board™, special tabulations (2011) from U.S. Patent and Trademark Office (USPTO), Patent Grant Bibliographic Data, and Thomson Reuters, SCI and SSCI, http://www.thomsonreuters.com/products_services/science/.

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Conclusion

U.S. universities and colleges continue to be key performers of U.S. R&D, particularly for basic research. Academic spending on R&D has continued to increase yearly over the last 10 years, both in current dollar and inflation-adjusted terms. Academic R&D spending primarily supports basic research—it accounted for 75% in 2009, with another 21% supporting applied research and 4% for development—proportions that have been stable over the decade. The federal government has long provided the majority of funding for academic R&D, at 59% in FY 2009. This federal support has grown yearly over the last 10 years—although when adjusted for inflation, FYs 2006 and 2007 were years of real dollar declines. Academic R&D has also long been concentrated in just a few S&E fields. For decades, more than half of all academic R&D spending has been in the life sciences.

The structure and organization of academic R&D have also changed. Research-performing colleges and universities continued to expand their research space, particularly in the biological and medical sciences, which are the fields with the bulk of R&D expenditures.

Both the overall academic S&E doctoral workforce and the academic research workforce have continued to increase, although the change since 2006 was the smallest single-period increase on record. The life sciences accounted for much of the growth in the academic S&E doctoral workforce, and life scientists represented more than a third of academic S&E doctoral researchers in 2008. The growth in the number of new PhDs has outpaced the growth in the number of full-time faculty positions since the late 1980s, particularly among life scientists. The following long-term academic workforce trends continue: a relative shift of S&E doctorate holders away from full-time faculty positions toward other full-time positions, part-time positions, and (in some years) postdocs; a relative shift toward greater employment of women and minorities; a steadily increasing proportion of foreign-born faculty and postdocs; and a decline in share of academic researchers receiving federal support. Federal support has been less available to early career S&E doctoral faculty than to more established faculty, and the percentage of early career S&E faculty with federal support has declined since 1991.

The intimate links between research and U.S. graduate education, regarded as a model by other countries, helps to bring large numbers of foreign students to the United States, many of whom stay in the country after graduation. Academia has also been able to attract many talented foreign-born scientists and engineers into its workforce. In research institutions, foreign-born faculty who received their degrees in the United States approach half the total of all U.S. degrees granted in engineering and computer science.

Data on S&E research articles suggest that research is increasingly done in team settings: the number of authors per article has steadily increased over the past 20 years. Academic R&D is also becoming more international, and this trend is reflected in the data on S&E articles. U.S. academic scientists and engineers are collaborating extensively with colleagues in other countries—in 2010, nearly one-third of S&E articles with a U.S. author also had at least one coauthor from abroad, and U.S. authors appeared on more than 40% of all internationally coauthored articles.

Citation data indicate that U.S. scientific publications remain highly influential relative to publications from other countries. However, the relative volume of U.S. article output has not kept up with the increasing outputs of the European Union and several countries in Asia. In recent years, China has become the second-largest national producer of S&E articles.

Notes

1. For this discussion, the terms *universities and colleges, higher education,* and *academic institutions* are used interchangeably and include only those schools that grant a bachelor's or higher degree in science or engineering and spend at least $150,000 for separately budgeted R&D in S&E.

2. The academic R&D totals presented here exclude expenditures at the federally funded research and development centers (FFRDCs) associated with universities. Those expenditures are tallied separately and discussed in chapter 4. Nevertheless, the FFRDCs and other national laboratories (including federal intramural laboratories) play an important role in academic research and education, providing research opportunities for students and faculty at academic institutions and highly specialized, shared research facilities.

3. For the definitions used in National Science Foundation (NSF) surveys and a more complete discussion of these concepts, see the chapter 4 sidebar, "Definitions of R&D."

4. The academic R&D reported here includes separately budgeted R&D and related recovered indirect costs, as well as institutional estimates of unrecovered indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing.

5. Under the act the funding was to be obligated by the end of FY 2009. However, the expenditures for these projects could span several years.

6. Statistics on R&D performance can differ depending on whether the reporting is by R&D performers or R&D funders. There are a number of reasons for this difference; for a discussion see the chapter 4 sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

7. Federal grants, contracts, and awards from other sources that are passed through state and local governments to academic institutions are credited to the original provider of the funds.

8. The medical sciences include subfields such as pharmacy, neuroscience, oncology, and pediatrics. The biological sciences include subfields such as microbiology, genetics, epidemiology, and pathology. These distinctions may blur at times because the boundaries between fields often are not well defined.

9. Data reported on non-S&E R&D expenditures are lower-bound estimates (slightly) for the national totals because NSF did not attempt to adjust for the 2.7% nonresponse rate on this survey item. Also, only institutions that conducted at least $150,000 of S&E R&D were surveyed. The activities of institutions that do not perform S&E R&D (but may conduct substantial amounts of non-S&E R&D) are not reflected here.

10. Data on non-S&E R&D expenditures have been collected by NSF since FY 2003. However, the response rates on these items for the years prior to 2006 make trend analysis unreliable.

11. This financial pass through is far from a complete indicator, as it provides little indication of the nature of the collaborative relationships involved.

12. Research space here is defined as the space used for sponsored R&D activities at academic institutions that is separately budgeted and accounted for. Research space is measured in net assignable square feet (NASF). This is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls. Multipurpose space that is partially used for research is prorated to reflect the proportion of time and use devoted to research.

13. The S&E fields used in the NSF Survey of Science and Engineering Research Facilities are based on the National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP)—which is updated every 10 years (the current version is dated 2000). The S&E fields used in both the FY 2007 and FY 2009 Survey of Science and Engineering Research Facilities reflect the 2000 CIP update. For a comparison of the subfields in the FY 2005 and FY 2007 surveys, see the detailed statistical tables for S&E Research Facilities: FY 2007.

14. The S&T field and subfield definitions were updated to the 2000 CIP starting with the FY 2007 facilities survey. Therefore, some of the observed declines in research space for health/clinical sciences and physical sciences between FY 2005 and FY 2007 could reflect definition changes.

15. Because of rising capitalization thresholds, the dollar threshold for inclusion in the equipment category has changed over time. Generally, university equipment that costs less than $5,000 would be classified under the cost category of "supplies."

16. The "bricks and mortar" section of the Survey of Science and Engineering Research Facilities asks institutions to report their research space only. Therefore, the reported figures do not include space used for other purposes such as instruction or administration. In the cyberinfrastructure section of the survey, however, respondents are asked to identify all of their cyberinfrastructure resources, regardless of whether these resources were used for research or other functions.

17. Research-performing academic institutions are defined as colleges and universities that grant degrees in S&E and expend at least $1 million in R&D funds. Each institution's R&D expenditures are determined through the NSF Survey of Research and Development Expenditures at Universities and Colleges.

18. Unless specifically noted, data on S&E doctorate holders in this section come from the Survey of Doctorate Recipients, a biennial NSF survey. All numbers are rounded to the nearest 100. Small estimates may be unreliable.

19. The United States is unlike many other countries in the fraction of doctorate holders who are employed in academia. A comparison of 1990–2006 doctorate recipients in 14 countries for which data are available found that in most of these countries, more than half of doctorate holders were employed in academia, compared with 47% for the United States. Only the United States, Austria, and Belgium had substantial fractions of doctorate holders employed in the business sector, and the United States had one of the smallest fractions employed in government (Organisation for Economic Co-operation and Development 2009).

20. Respondents were presented with a list of work activities and asked to identify the activities which occupied the most and second most hours during the typical work week. This measure was constructed slightly differently prior to 1993, and the data are not strictly comparable across the two periods. Prior to 1993, the survey question asked the respondent to select the primary and secondary work activity from a list of activities. Beginning in 1993, respondents were asked on which activity they spent the most hours and on which they spent the second most hours. Therefore, the crossing over of the two trends between 1991 and 1993 could partly reflect a difference in methodology. However, the faster growth rate for researchers in both the 1973–91 and 1993–2008 periods means that changes in question wording cannot fully explain the observed trend. Because individuals may select both a primary and a secondary work activity, they can be counted in both groups.

21. On the 2006 Survey of Doctorate Recipients, respondents were asked to indicate whether they "Work with an immediate work group or team?"; "Work with others in the same organization (company, university, agency, etc.), but not the same group or team?"; "Work with individuals in other organizations in the U.S.?"; and "Work with individuals located in other countries?" For respondents who indicated that they had collaborated with individuals located in other countries, subsequent questionnaire items inquired about the nature of the collaboration (for example, sharing information, sharing facilities, preparing a joint publication) and the mode of collaboration (for example, collaboration via telephone or e-mail, travel to foreign country).

22. These data include only U.S.-trained postdocs employed in U.S. academic institutions. A 2003 survey conducted by the Sigma Xi honor society, which was non-representative and likely to undercount foreign-degreed postdocs, found that 46% of responding postdocs had received their doctorate from a non-U.S. institution.

23. Interpretation of the data on federal support of academic researchers is complicated by a technical difficulty. Between 1993 and 1997, respondents to the Survey of Doctorate Recipients were asked whether work performed during the week of April 15 was supported by the federal government. In most other survey years, the reference was to the entire preceding year, and in 1985, it was to the month of April. However, the volume of academic research activity is not uniform over the entire academic year. A 1-week (or 1-month) reference period seriously understates the number of researchers supported at some time during an entire year. Thus, the numbers for 1985 and 1993–97 cannot be compared with results for the earlier years or with those from the 1999 through 2008 surveys, which also used an entire reference year.

The discussion in this edition of *Indicators* generally compares data for 2008 with data for 1991. All calculations express the proportion of researchers with federal support relative to the number responding to this question. The reader is cautioned that, given the nature of these data, the trends discussed are broadly suggestive rather than definitive. The reader also is reminded that trends in the proportion of all academic researchers supported by federal funds occurred against a background of rising overall numbers of academic researchers.

24. Publication traditions in broad S&E fields differ somewhat. For example, computer scientists often publish their findings in conference proceedings, and social scientists often write books as well as publish in journals. Proceedings and books are poorly covered in the data currently used in this chapter.

25. The U.S. sector identification in this chapter is quite precise; to date, sector identification has not been possible for other countries.

26. Statements that a country "authors" a certain number of articles are somewhat imprecise, especially given the growing rates of international collaboration discussed later in this chapter. This chapter follows the convention of counting a country's articles in fractions (i.e., articles with more than one country's participation are fractionalized according to the number of different institutional authors listed on the article). These fractions are then allocated to the respective

country and totaled to produce a national article count. This chapter uses the more straightforward if less precise terminology "country X produces some *number* of the world's S&E articles." It also refers to the percentage of the world's total S&E articles accounted for by certain countries.

27. For example, Vatican City is not strictly a country; the Union of Soviet Socialist Republics (USSR) and Hong Kong are contained in the data in earlier years, but the USSR no longer exists and Hong Kong data are now reported as part of China. See appendix table 5-25 for a list of the locations represented in the data.

28. Distributions of data in which a small percentage of cases account for a significant amount of the total value across all cases belong to a group of statistical distributions collectively referred to as *power law distributions* (Adamic, 2000). Examples of other phenomena with such distributions include earthquakes (only a few among a large number of earthquakes have great power) and Internet traffic (visits to a relatively small number of sites account for a very large proportion of visits to all sites).

29. Coauthorship is a broad, though limited, indicator of collaboration among scientists. Previous editions of *Indicators* discussed possible underlying drivers for increased collaboration, including scientific advantages of knowledge- and instrument-sharing, decreased costs of travel and communication, and national policies (NSB 2006). Katz and Martin (1997), Bordons and Gómez (2000), and Laudel (2002) analyze limitations of coauthorship as an indicator of research collaboration. Despite these limitations, other authors have continued to use coauthorship as a collaboration indicator (Adams et al. 2005; Gómez, Fernández, and Sebastián 1999; Lundberg et al. 2006; Wuchty, Jones, and Uzzi 2007; Zitt, Bassecoulard, and Okubo 2000).

30. The reader is reminded that the data on which these indicators are based give the nationality of the institutional addresses listed on the article. Authors themselves are not associated with a particular institution and may be of any nationality. Therefore the discussion in this section is based on the nationality of institutions, not authors, and makes no distinction between nationality of institutions and nationality of authors.

31. For a consideration of current limitations in identifying interdisciplinary S&E research using bibliometrics techniques, see Wagner et al. (2011) and the sidebar "Can Bibliometric Data Provide Indicators of Interdisciplinary Research?" in NSB 2010.

32. Readers are reminded that the *number* of coauthored articles between any pair of countries is the same; each country is counted once per article in these data. However, countries other than the pairs discussed here may also appear on the article.

33. Finland is included here as one of the Scandinavian countries. Iceland is not.

34. Article counts in this section are based on the year in which the article appeared in the database, not on the year of publication, and therefore are not the same counts as in the earlier discussion of total world article output.

35. The 16 FFRDCs sponsored by the Department of Energy dominated S&E publishing by this sector. Across all fields of S&E, DOE-sponsored labs accounted for 83% of the total for the sector in 2005 (NSB 2008). Scientists and engineers at DOE-sponsored FFRDCs published 96% of the sector's articles in chemistry, 95% in physics, and 90% in engineering (see "S&E Articles From Federally Funded Research and Development Centers," NSB 2008, p. 5–47). Nine other federal agencies, including the Departments of Defense, Energy, Health and Human Services, Homeland Security, Transportation, and Treasury; the National Aeronautics and Space Administration; the Nuclear Regulatory Commission; and National Science Foundation also sponsor another 23 FFRDCs (NSF/SRS 2009).

36. Identification of the sector of the non-U.S. institution is not possible with the current data set.

37. Readers are reminded that coauthors from different departments in an institution are coded as different institutions.

38. This chapter uses the convention of a 3-year citation window with a 2-year lag. For example, 2008 citation rates are from references in articles in the 2008 data file to articles contained in the 2004, 2005, and 2006 data files of the Thomson Reuters Science Citation Index and Social Sciences Citation Index databases. Analysis of the citation data shows that, in general, the 2-year citing lag captures the 3 peak citation years for most fields, with the following exceptions: in astronomy and physics, the peak citation years are generally captured with a 1-year lag, and in computer sciences, psychology, and the social sciences with a 3-year lag.

39. "Influence" is used here broadly; even citations that criticize or correct previous research indicate the influence of that previous research on the citing article.

40. Because different S&E fields have different citation behaviors, these indicators should be used with caution. For example, articles in the life sciences tend to list more references than, for example, articles in engineering or mathematics. Thus, a country's research portfolio that is heavily weighted toward the life sciences (e.g., the U.S.) may receive proportionately more citations than a country whose portfolio is more heavily weighted toward engineering or mathematics.

41. The reader is reminded that articles in this section are counted by the year they entered the database, not by year of publication. Therefore article counts, and percentages based on them, are different from the data presented earlier in this section.

42. Some part of this percentage decrease may reflect the *increase* in Chinese journals in the SCI and SSCI databases used in this chapter. Since more Chinese authors in these journals are available to cite their Chinese coauthors, international citations to Chinese-authored articles is declining as a share of total citations. However, accounting for the "nationality" of a journal is not straightforward, and the data file used by NSF excludes journals that are primarily of regional interest. NSF's count of "Chinese" journals shows

an increase of 75% over the past decade, compared to an increase of 334% for Chinese-authored articles.

43. Percentiles are specified percentages below which the remainder of the articles falls. For example, the 99th percentile identifies the number of citations 99% of the articles failed to receive. For example, across all fields of science, 99% of articles from 2005 to 2007 failed to receive at least 21 citations in 2009. Matching numbers of citations with a citation percentile is not precise because all articles with a specified number of citations must be counted the same. Therefore, the citation percentiles discussed in this section and used in appendix tables 5-44 and 5-45 have all been counted conservatively, and the identified percentile is in every case higher than specified, (i.e., the 99th percentile is always greater than 99%, the 95th percentile is always greater than 95%, and so forth). Actual citations/percentiles per field vary widely because counts were cut off to remain within the identified percentile. For example, using this method of counting, the 75th percentile for engineering contained articles with three to four citations in 2005 through 2007, whereas the 75th percentile for astronomy contained articles with 6 to 10 citations.

44. For an overview of these developments in the 20th century, see Mowery (2002).

45. Sharp changes in the number of patents granted are related to the speed of processing at United States Patent and Trademark Office.

46. The institutions listed in appendix table 5-46 are slightly different from those listed in past volumes, and data for individual institutions may be different. In appendix table 5-46, an institution is credited with a patent even if it is not the first assignee, and therefore some patents may be double counted. Several university systems are counted as one institution, and medical schools may be counted with their home institution. Universities also vary in how they assign patents (e.g., to boards of regents, individual campuses, or entities with or without affiliation with the university).

47. The patent counts reported by Association of University Technology Managers respondents in figure 5-32 and appendix table 5-48 cannot be compared with the patent counts developed from USPTO data as in appendix tables 5-46 and 5-47.

48. Patent-based data must be interpreted with caution. Year-to-year changes in the data may reflect changes in USPTO processing times (so-called "patent pendency" rates). Likewise, industries and companies have different tactics and strategies for pursuing patents, and these may also change over time.

Patent citations to S&E research discussed in this section are limited to the citations found on the cover pages of successful patent applications. These citations are entered by the patent examiner, and may or may not reflect citations given by the applicant in the body of the application. Patent cover pages also contain references to scientific and technical materials not contained in the article data used in this chapter (e.g., other patents, conference proceedings, industry standards, etc.). Analyses of the data referred to in this section found that nonjournal references on patent cover pages accounted for 19% of total references in 2008. The journals/articles in the SCI/SSCI database used in this chapter—a set of relatively high-impact journals—accounted for 83% of the journal references, or 67% of the total science references, on the patent covers.

49. Pilot Program for Green Technologies Including Greenhouse Gas Reduction, 74 Fed. Reg. 64,666 (USPTO, December 8, 2009).

50. Due to data limitations, this discussion is limited to the following: patent data are patent awards made by the USPTO to all assignees, not just U.S. assignees. S&E publication data are for all publications in all U.S. sectors and all country authors.

51. Compare with Organisation for Economic Co-operation and Development, 2010, p.36.

Glossary

Academic doctoral S&E workforce: Includes those with a U.S. doctorate in an S&E field employed in 2- or 4-year colleges or universities in the following positions: full and associate professors (referred to as *senior faculty*); assistant professors and instructors (referred to as *junior faculty*); postdocs; other full-time positions such as lecturers, adjunct faculty, research associates, and administrators; and part-time positions of all kinds.

Academic institution: In the Expenditures and Funding for Academic R&D section of this chapter, an academic institution is generally defined as an institution that grants a bachelors' or higher degree in science or engineering and that has spent at least $150,000 for separately budgeted R&D in S&E within the fiscal year being measured. Elsewhere in the chapter, this term encompasses any accredited institution of higher education.

Underrepresented minority: Demographic category including blacks, Hispanics, and American Indians/Alaska Natives; groups considered to be underrepresented in academic institutions.

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Errata

Updated 16 February 2012

The following errors were discovered after publication of the print and PDF versions of *Science and Engineering Indicators 2012* and *Science and Engineering Indicators Digest 2012*. These errors have been corrected in the online version of the volume and in the interactive *Digest*.

Chapter 5

Page 5-11. The appendix table reference in the "Industry funds" bullet is incorrect. It should be appendix table 4-3.

Figure 5-33. The units label was omitted. Units shown are percentages.